1.00 INTRODUCTION

1.10 AUTHORIZATION

The Massachusetts Department of Environmental Management (DEM) - Office of Water Resources (OWR) has contracted GZA GeoEnvironmental, Inc. of Norwood, Massachusetts (GZA) to conduct the Jones River Watershed Study - DEM Contract RFR 596. This study was funded by and conducted in conjunction with the South Coastal Basin Team as part of the Massachusetts Executive Office of Environmental Affairs (EOEA) Watershed Initiative, which gathers essential data and information needed for planning future watershed management. This report is subject to the Limitations in **Appendix A**.

1.20 PURPOSE

The purpose of this study is to prepare a water use inventory and conduct an inflow/outflow analysis for the Jones River watershed and its subbasins (i.e., study area). This analysis considers the potential human and natural influences which affect the overall water budget of the study area. Factors considered include, among others, climate and weather patterns, watershed characteristics, groundwater and surface water hydrology, local flora and fauna, water supply withdrawals, population, and anticipated growth. By analyzing the quantities of water entering and exiting the watershed, an approximate water budget was estimated, which accounts for available water resources in and around the Jones River and its tributaries.

As growth continues and water demand increases, careful planning is needed to manage and protect the state's water resources in a sustainable and beneficial manner. This study was designed as a first step in assisting watershed planners, local governments, state regulators, private industry, and local stakeholders in understanding local hydrologic and aquatic habitat characteristics and identifying key water resources management issues in the Jones River watershed.

1.30 SCOPE

This report summarizes existing information gathered as part of the Jones River Watershed Study and the development of a simple, subbasin-level, monthly water budget for the Jones River watershed. The water budget estimates monthly streamflows in the river under current, natural, and future conditions. The watershed water budget allows for the estimation of available yields with consideration for aquatic habitat maintenance, living aquatic habitat resources, and other water supply issues. GZA applied similar available yield estimation procedures as part of the Weir River Watershed Study (DEM RFR 452). The available yield estimate compares the hydrologic characterization of the watershed under natural conditions to published target streamflow values.

This study was undertaken as a part of the Massachusetts Watershed Initiative (MWI). The MWI is a broad partnership of state and local agencies, conservation organizations, businesses, and municipal officials. The goals of the MWI are to: (a) improve water quality; (b) restore natural flows to rivers; (c) protect and restore biodiversity; (d) improve public access and balanced resource use; (e) improve local capacity to protect their water resources; and (f) promote shared responsibility for watershed protection and management. The MWI acknowledges as a key to successful program implementation the co-leadership roles of the state, watershed associations or other citizens groups, the business community, and municipalities. This report should be seen as a tool to be used by these stakeholders.

The development of this report involved the collection and review of existing reports and data, as well as conducting interviews with key watershed stakeholders. Sources of such information include the DEM, the Massachusetts Department of Environmental Protection (DEP), the Town of Kingston and City of Brockton, the Jones River Watershed Association, the Old Colony Planning Council (OCPC), the Cape Cod Cranberry Growers Association (CCCGA), the U.S. Geological Survey (USGS), National Climatic Data Center (NCDC) and others. As a part of this task, a bibliography of pertinent sources has been produced and included in this report as Section 8.00. In addition, data obtained from the USGS stream gage on the Jones River at Elm Street was used for the development of flow duration curves and evapotranspiration estimates were also developed based on climate data from the NCDC.

1.40 METHODOLOGY

The climatology and hydrology data gathered provided the means to estimate the monthly water budget of each subbasin. The water budget, a simple accounting of the inflows and outflows of the watershed, is built upon the relationships described in the hydrologic cycle (Section 3.0) which can be presented as a simple equation relating precipitation, evapotranspiration, surface runoff, groundwater outflow/baseflow, diversions/withdrawals, and changes in basin storage volume. From this relationship, a spreadsheet-based model using a monthly time-step can be developed for application to a particular basin. Similar methods were used to develop the water budget for the Weir River Watershed Study (DEM 452). A detailed description of the analytical method can be found in Appendix B.

1.50 GENERAL LIMITATIONS

This report was prepared in accordance with the scope developed by the DEM in their Request for Response (RFR DEM 596), which was discussed in Section 1.30.

In general, this report provides a broad overview of both the natural features of the watershed and the current level of water resources development. This information is intended to inform stakeholders about the water resources of the basin and identify the users and beneficiaries of these resources. This report presents the results of a generalized water budget and qualitative in-stream habitat study. This information is intended to be useful in identifying general areas of concern within the basin, in terms of stresses on both water supplies and aquatic habitat. It is our intent that the data generated will spur discussion and interaction between stakeholders within the watershed regarding prioritization of water resources allocation.

The water budget developed by GZA for this study is a generalized model using average monthly conditions over large scale geographic areas. Due to the lack of published long term, sub-basin-specific surface water and groundwater data, numerous hydrologic characteristics were approximated from information collected in previous reports, at the USGS stream gage at Elm Street, and/or nearby, similar watersheds. Neither detailed stochastic studies of water inflows and demands, nor detailed operational studies of water supply wells and reservoirs were conducted as part of our contracted scope of work. While these types of investigations are generally used by water suppliers to evaluate the capacities of their systems, the current study deals with the more qualitative interaction between water supply and the environment.

The northern fringe of the Plymouth-Carver aquifer underlies the southern portion of the Jones River watershed. The subsurface materials, primarily sands and/or gravels, and the presence of the Plymouth-Carver aquifer are indications that groundwater and surface water divides may be disparate. However, because the limited scope and available resources of this project preclude detailed groundwater modeling and hydrogeologic data collection, the surface water and ground water divides are assumed to coincide.

1.60 ACKNOWLEDGEMENTS

The project team would like to acknowledge the assistance of several individuals who were invaluable in the preparation of this study and report: Mr. Mike Gildesgame and Ms. Linda Marler of the Department of Environmental Management; Mr. George Zoto, of the Executive Office of Environmental Affairs; Ms. Pine duBois of the Jones River Watershed Association; Mr. Jeff LaFleur of the Cape Cod Cranberry Growers Association; Mr. James Watson of the Old Colony Planning Council, Mr. Matthew Darsch of the Town of Kingston Water Department; and Mr. Brian Creedon of the City of Brockton.

2.0 WATERSHED DESCRIPTION

2.10 GENERAL WATERSHED DESCRIPTION

The Jones River Watershed, designated as "21b" on the Massachusetts Water Resources Commission master list, is located within the South Coastal Basin of Massachusetts. The watershed encompasses much of Kingston, and parts of Plympton, Pembroke, Duxbury, Halifax and Plymouth. A summary of land area for each community within the watershed is provided in **Table 2-1**. The locus of the watershed is shown on **Figure 2-1**. The composite watershed orthophoto is shown in **Figure 2-2**. The western-most limits of the watershed extend slightly beyond Silver Lake into eastern Halifax, while the southern limits extend near the borders of the Towns of Kingston and Plympton, and the northern limits extend through southwestern Duxbury and central and southern Pembroke.

Silver Lake, the largest body of fresh water in the study area, provides the headwaters for the Jones River, as well as the drinking water supply source for the City of Brockton via inter-basin transfer. The Jones River flows about 7.5 miles east from Silver Lake to Plymouth Bay, draining an area of approximately 30 square miles. The river is flanked by wetland areas along the tidal areas of its mouth, with typical coastal rolling hill topography in the uplands.[1] The Upper Jones River, just downstream of the dam at Forge Pond (southeast of Silver Lake), is reportedly seasonally dry. In the recent past (1999 to 2001), the period of dryness has encompassed most of the year, perhaps a result of lower than normal precipitation. The river begins to flow as it receives flow from tributaries such as Pine Brook and Howard Brook, as well as groundwater outflow (baseflow). Groundwater outflow is often prominent in the basin due to the prevalence of stratified drift, particularly near the northern fringes of the Plymouth-Carver aquifer in the southern portion of the watershed.

The Plymouth-Carver Aquifer is the second largest aquifer in Massachusetts, occupying an area of 140 square miles. It is comprised primarily of saturated glacially-deposited sands and gravels that are almost entirely dependent upon precipitation for recharge. The aquifer loses water through processes of evapotranspiration, seepage to streams, bogs, lakes, ponds, brooks, pumping, and direct evaporation from the water table.[2] It is designated as a sole-source drinking water supply aquifer by the Environmental Protection Agency (EPA). Although the highest yield portions of the aquifer lie outside of the watershed boundaries, the northern fringes of the aquifer are indistinguishable from the underlying stratified drift deposits in southern Kingston.

[1] Massachusetts Department of Environmental Management Division of Water Resources. "North-South-Jones River Basin: Inventory and Analysis of Current and Projected Water Use" July, 1988.

[2] Hansen, Bruce P. and Lapham, Wayne W. "Geohydrology and Simulated Ground-Water Flow, Plymouth Carver Aquifer, Southeastern Massachusetts." US Geological Survey, Water Resources Investigations Report 90-4204, 1992.

The most prevalent land use designation within the basin is wooded, followed by residential. The basin is mostly underlain by stratified drift (i.e., sand and gravel) deposits, which makes it ideal for cranberry bog operations.

2.20 WATERSHED AND SUB-BASIN AREAS

The Jones River watershed drains approximately 29.8 square-miles (mi^2) from Tubbs Meadow Brook to Kingston Bay. The fresh water portion of the basin is about 26.9 mi^2 to the Elm Street Dam (including Halls Brook and Smelt Brook subbasins). In its developed (present) state, the water resources of the basin are utilized for in-basin and inter-basin water supply and agricultural purposes, which has changed, to an extent, the size and configuration of the watershed and its subbasins. A description of water supply sources and the inter-basin transfer is provided in Section 4.0.

For use in developing hydrologic budget estimates, GZA has divided the Jones River watershed into discrete sub-areas. The bounds of the watershed were obtained from MassGIS as an ArcView shapefile and reviewed by GZA. The GIS layer depicts subbasin boundaries which were delineated by the USGS based on existing USGS stream gages and drinking water supply sources. Building on the existing data layer, GZA has refined the subbasin boundaries based on topography, existing storm drainage networks (see Section 4.40), cranberry bog operations, and the outlet locations of major tributaries. Accordingly, GZA subdivided the watershed into 8 subbasins representing the following drainage areas:

- Silver Lake;
- Pine Brook;
- Halls Brook;
- Jones River Brook;
- Furnace Brook;
- Smelt Brook;
- Jones River from Silver Lake outlet to Elm Street (Upper Jones River); and
- Jones River—Tidal from Elm Street to Kingston Bay.

Note that groundwater divides may not necessarily coincide with the surface water divides (refer to Section 3.43).

The subbasins range in size from 2.25 to 4.80 square miles as shown in **Table 2-2** And **Figure 2-3**. A small portion of the Pine Brook subbasin, comprising the drainage area of Upper Chandler Pond, has the potential to discharge either southward into Pine Brook or northward to the South River Watershed depending on the operational practices of a local bog owner. The Silver Lake subbasin contributes to the Jones River sporadically, depending on the operational practices of the City of Brockton and its water supply system. The City of Brockton imports water to and diverts water from Silver Lake to its water supply system, which strongly influences fluctuating lake levels which are usually below the level of the spillway at Forge Pond Dam. See Section 4.00 for a detailed description of current water supply practices, including inter-basin transfers.

2.30 TOPOGRAPHY

The topography of the region was sculpted by the Wisconsinan glacial sheet that began its last retreat about 15,000 years ago. Most of the higher landforms are glacial drumlins, gently rounded, rolling hills composed of varying amounts of till with bedrock outcrops. The valleys were carved during the ice advance. By about 14,000 years ago, the last glacial sheet had retreated to a position north of what is now Boston. During the melting of the glacial ice, many of the valleys in the Kingston area were filled with stratified drift; the pervious well sorted and layered deposits formed from sediment carried by alternating melt-water flows from the glacier. The elevation of the watershed ranges between 0 to 200 feet above a datum of sea level, with the higher areas in the southern portions, sloping down to lowlands between 0 ft and 50 ft above sea level in the central portion of the watershed along the river, and climbing back up to 100 feet above sea level in the northern portions. The area of highest elevation is found just to the southeast of Indian Pond in the Town of Kingston.

2.40 HYDROGRAPHY

The main water course in the watershed is the Jones River, formed (under natural conditions) by outflows from Silver Lake. There are several tributaries that contribute to the flow of water in the Jones River, including Jones River Brook, Pine Brook, Howard Brook, Halls (also referred to as Stony) Brook, Furnace Brook, and Smelt Brook (**Table 2-3**). Smelt Brook empties at/near the mouth of the Jones River and Halls Brook confluences slightly upstream of the mouth of the river and just downstream from Kingston center. Pine Brook and Jones River Brook enter the river far upstream, contributing a seasonably varied amount of flow.

The main stem of the Jones River is a low gradient stream, typical of coastal riverine systems in Southeastern Massachusetts. The Jones River drops from an elevation of approximately 47 feet (NGVD) at Silver Lake to sea level (0 feet) in its approximately 7.4-mile-long course to Kingston Bay. Tributaries to the Jones have relatively steeper gradients of around 40 to 60 feet/mile, particularly in the southern portion of the watershed on Smelt Brook and Furnace Brook.

The watershed region contains numerous lakes and ponds which are shown in **Figure 2-4** and summarized in **Table 2-4.** In general, the southeastern area of the watershed contains the greatest abundance of surface water. The southwest and northeast regions have large wetland areas that have formed in the floodplain alluvium deposits, and small wetland areas are scattered over the entire watershed. Cranberry bogs can be found throughout the watershed and also play a role in the variable flow in the areas surrounding the Jones River.

The watershed is tidal from the Elm Street Dam downstream to the mouth of the Jones

River at Kingston Bay. The tidal portion of the Jones River, about 2.7-miles in length, winds past Routes 3A/53 and Route 3, as well as downtown Kingston. The tidal range is expected to be about 10 feet under normal conditions, but has been reported to reach the USGS stream gage at Elm Street during extreme tidal surges. A number of small tributaries to the Jones River are also tidally influenced, including portions of Hall Brook and Smelt Brook to the Foundry Pond Dam.

2.50 GEOLOGY

Bedrock Geology

The bedrock geology of the watershed consists of basement igneous rocks showing varying degrees of metamorphism and a small area of sedimentary rocks located in the south-central portion. The overburden soils are of glacial origin, a mixture of stratified drift and outwash plains to the east and south, glacial tills and bedrock to the northwest, and large sand deposits and outwashes to the southwest.

Surficial Geology

About 83.8 percent of the watershed is underlain by stratified drift. Only about 4.5 percent of the watershed surficial geology is till or bedrock, and the remaining portions of the watershed consist of floodplain alluvium or open water. **Table 2-5** presents percentages of surficial geology in each subbasin. MassGIS classifies the surficial geology in terms of Sand and Gravel, Till and Bedrock, Sandy Till over Sand, End Moraines, Large Sand Deposits, and Floodplain Alluvium.

The extensive amounts of surficial deposits blanketing the Jones River Watershed area, as well as most of New England, are a result of the series of glacier advancements and retreats. Left behind by glaciation processes are two major types of soil classified as till and stratified drift, as well as predominant structures known as moraines and outwash plains (**Figure 2-5**). Stratified drift is a layered, moderately to well sorted glacial meltwater deposit composed of coarse sands and gravels that are very pervious and generally favorable to the development of groundwater supplies. Till is a very dense, poorly sorted, relatively impervious soil composed of clay, silt, sand, gravel, cobbles and boulders deposited directly from the underside of a glacier. A moraine is a collection of sediments or “dirty ice” that forms along the edges of a glacier as it moves. As a glacier retreats, the load of sediments, or till, is left at the margin of melting, thus creating a moraine. An outwash plain consists of broad, almost flat, alternating layers of sand and gravel built up by shifting streams of glacial meltwater.

Most of the Jones River Watershed is covered with sand and gravel typical of the stratified drift found covering much of southeastern New England. The eastern and southwestern portions contain large deposits of floodplain alluvium, and in general, there are small floodplain deposits scattered throughout the northern section. In central Kingston, there are large sand deposits amongst sand and gravel. Most of the bedrock outcrops can be observed in the northern portion of the watershed, where the sand and gravel deposits are not as thick.

The northern region of the watershed is characterized primarily by stratified drift, with thick deposits of sand and gravel prevalent in western Pembroke and eastern Duxbury. In southeastern Pembroke the remains of the former glacial Taunton Valley Lake can be observed in surviving delta deposits.[3] Much of Duxbury is comprised of till overlying sand and gravel deposits. In general, the southern portion of the watershed spanning the southern parts of Kingston and eastern Plympton, is abundantly covered with the sands and gravels of stratified drift, as well as a smaller amount of outwash plains and deltas, and some large sand deposits. The central portion of the watershed, namely northern Kingston and northern Plympton contain a mixture of delta outwashes, stratified drift, and large sand deposits. To the west, the landscape is generally characterized by the drumlin hills of till and bedrock with remnants of outwash plains and deltas surviving in the valleys.

The US Natural Resources Conservation Service (formerly the Soil Conservation Service) soil survey of Plymouth County shows that the majority of the soils in the Jones River watershed are part of the Hinckley-Merimack-Muck association. These soils are described as deep, excessively drained to well–drained soils formed in sand and gravel; and deep, very poorly drained organic soils in outwash areas.

2.60 LAND USE

Land in the watershed is approximately 52.4 percent forested and 22.0 percent residential (**Figure 2-6**). The land use percentages of the watershed are provided in **Table 2-6A**. Approximately 5.1 percent of the watershed is covered by water and about 4.9 percent of the watershed is comprised of cranberry bog.

Impervious areas, especially connected impervious areas, can increase the amount of runoff in a basin and impair the amount of recharge to groundwater supplies. **Table 2-6B** shows an estimate of impervious area in the Jones River watershed, based on land use classifications and NRCS guidelines. The data indicates that the fresh water portion of the basin contains a total of less than 10 percent imperviousness, and most of that is a result of residential development (i.e., roofs, driveways, roads) which is likely not a major influence on runoff-recharge relationships.

2.70 FLORA AND FAUNA

The Jones River watershed provides habitat for a variety of flora and fauna and contains many important natural wildlife areas, including vernal pools and rare species habitat. The river also provides for anadromous fish runs, allowing species of fish that live in the sea to

[3] Persky, James H. "Yields and Water Quality of Stratified-Drift Aquifers in the Southeast Coastal Basin, Cohasset to Kingston, Massachusetts." US Geological Survey, Water Resources Investigations Report 91-4112, 1993.

return to inland waters to spawn. **Figure 2-7** shows sensitive environmental areas and wildlife habitats in the watershed and **Figure 2-8** identified approximate wetland areas. The watershed also contains considerable agricultural development in the form of cranberry bogs (see Section 4.20).

Fisheries sampling was conducted by the Division of Marine Fisheries' Steve Hurley in October, 1998. Fisheries sampling results indicated populations typical for low-gradient coastal Southeastern Massachusetts streams. A number of species were found including American eel, bluegill, sunfish, largemouth bass, tessellated darter, yellow perch, redfin pickerel, chain pickerel, and brook trout. Brook trout are stocked in the spring, although in the past the river reportedly supported a native trout population (Jones River Watershed Association, Silver Lake & Jones River Watershed Study, 2000), as well as anadromous fish species. Spawning white sucker were observed during GZA field reconnaissance in April, 2002.

As described in the Silver Lake and Jones River Watershed Study by the Jones River Watershed Association (JRWA), 2000, macroinvertebrate sampling took place in late September/early October 1998 based on protocol established in Hicks (1997). This extensive report focused on macroinvertebrate and quantitative and qualitative field habitat assessments. The report states that habitat assessment was completed simultaneously by Teal, Peterson, and Reid, in accordance with DEP biomonitoring protocol. Macroinvertebrate sampling results from 1998, 1999, and 2000 indicated a range of 6 to 23 families within the watershed, with the highest number of families occurring at Pine Brook. A number of the common indices used in biometric calculations reportedly did not reveal consistent or reliable results, indicating results were inconclusive. The report concluded the area of the Jones River downstream of Forge Pond Dam had the lowest benthic invertebrate scores (as per biomonitoring protocols) as compared to other reaches within the watershed. Habitat assessments were also included in the report, based on ten field-observed variables as bottom substrate/available cover, pool variability, channel alteration and sinuosity, etc. and indicated "sub-optimal" conditions in Jones River Brook and Howard Brook. However, it should be noted that many of the streams within the watershed have been historically channelized by former mills, or are simply low-gradient, warm-water streams that naturally do not provide extensive habitat variability.

Silver Lake provides habitat for two rare species of mussel: Eastern Pond Mussel (*Ligumia nasuta*) and Tidewater Mucket (*Leptodea ochracea)*. A 1992 survey of Eastern Massachusetts for the Eastern Pond Mussel conducted for the Massachusetts Natural Heritage Program, included Silver Lake. The study found that Silver Lake has a dense population of the rare Eastern Pond Mussel, as the author found a density of 220 individuals per hour of observation. Although quantification of the Tidewater Mucket was not specifically a task of the survey, dense populations of this species were also observed at Silver Lake. The mean shell size of the Eastern Pond Mussel collected as part of the survey was the second lowest of the 19 sites sampled, and were found to be clustered about the mean size of 60 mm (i.e., little variation in size). The study did not draw conclusions as to the reasons for the density or size, but recommended further study, including age analysis. The author also anecdotally observed that the Eastern Pond Mussel may prefer deeper water (15-20 feet) and finer sediments than found in many littoral zones.

Fresh water Eastern Pond and Tidewater Mucket mussels and spent shells at Silver Lake were also surveyed in 1999 as described in the JRWA's Silver Lake and Jones River Watershed Study. The sampling effort entailed 45-minute collection efforts on nine separate days from August 30 to October 14, as the water levels of Silver Lake were reportedly receding. Results of the 1999 sampling effort indicated a general decrease in shell size of stranded mussels with time. In 1997, Normandeau Associates sampled live mussels in Silver Lake. Results of the Normandeau study suggested most of the mussel population dwelled in waters deeper than 17 feet from the USGS-listed lake level (i.e., elevation 47 feet). The JRWA's Silver Lake and Jones River Watershed Study has suggested that collections of stranded mussels in 1999 suggest smaller size mussels and younger age classes were not well represented by the Normandeau Study, and lake level fluctuations may have an impact on such classes.

2.80 POPULATION

Table 2-7 and Table 2-8, respectively, present pertinent population statistics and population trends for the Towns of the watershed, as well as the Towns outside of the watershed which use water withdrawn from within the watershed. Data was obtained from the U.S. Census Bureau, the Metropolitan Area Planning Council (MAPC), and the EOEA. The six Towns of the watershed have a total (2000) population of about 104,800. Note that the Town of Plymouth accounts for almost half of the total population. However, essentially none of the residents of Plymouth actually live in within the boundaries of the Jones River Watershed. Approximately 16,910 persons live within the limits of the watershed based on population density and the area of each Town in the watershed. About 142,000 additional persons in Brockton, Hanson, and Whitman use water withdrawn from the watershed, to varying extents. Water usage is further discussed in Section 4.20.

The MAPC population forecast for communities within the watershed predicts a 47-percent increase from about 104,800 to about 134,250 in the year 2020. Conversely, population projections for Brockton, Hanson, and Whitman predict a decrease from 117,680 to 115,270 by 2020. The EOEA Buildout projects a population of 189,800 for the watershed communities and 178,590 for Brockton, Hanson, Marshfield, and Whitman. The Buildout represents a population growth (from current levels) of 81 percent within the watershed and 26 percent for the communities of Brockton, Hanson, Marshfield, and Whitman.

3.00 HYDROLOGY

Stream flow, precipitation, and hydrogeologic data summarized below form the basis of the hydrologic description of the Jones River Watershed. GZA's simplified water budget model derived, in part, from the existing data, consists of a monthly inflow/outflow analysis of each subbasin, using published precipitation, streamflow, and other hydrologic data to estimate key parameters of the hydrologic cycle (i.e., base flow, runoff, etc.). The data summarized below is an important part of the simplified water budget model, as it serves to calibrate and verify the model estimates in light of observed conditions.

3.10 THE HYDROLOGIC CYCLE

The hydrologic cycle represents the natural process in which water is continually circulated and transformed. **Figure 3-1** is a schematic representation of the various elements which comprise the hydrologic cycle. The natural, average annual cycle can be represented by the following equation:

$$P = (SW_R + GW_R) + ET$$

where: P = Precipitation
SW_R = Surface Water (Direct) Runoff
GW_R = Groundwater Runoff (i.e. recharge)
ET = Evapotranspiration

It is important to understand the concepts of total streamflow, surface runoff, and baseflow, and the differences between them. Total streamflow is the sum of groundwater and surface water runoff under steady state conditions (i.e., when the incremental change in aquifer storage is zero), groundwater recharge is approximately equivalent to baseflow. Baseflow is considered to be the result of groundwater discharging to surface water (i.e., streams). The magnitude of baseflows will usually vary with changes in aquifer storage, climate conditions, and other natural and human influences. On an average annual basis, the volume of baseflow in a given stream is often considered to be representative of average annual groundwater recharge. Whereas baseflows are a more or less continuous source of total streamflow, surface water runoff is the result of precipitation falling and flowing over-land into water bodies (i.e., streams). Surface water runoff often constitutes a significant portion of average total stream flow, but is more temporally variable in nature than baseflows, since it is heavily dependent on the volume and intensity of a discrete precipitation event. There is technically an "in-between" contribution to total streamflow which is called "interflow." Interflow consists of water which has infiltrated into the subsurface, but discharges to a stream or other water body prior to reaching the water table. Therefore, it is not quite surface runoff, nor does it technically qualify as baseflow. Consult the Glossary in Section 7.00 for definitions of other various hydrologic terms used within this report.

3.20 HYDROLOGIC BACKGROUND INFORMATION

3.21 Climate Stations

GZA assembled data from a variety of climate stations in and around the watershed to help better describe the climatology and hydrology of the Jones River watershed. Locally, the National Weather Service (NWS) operates hourly (i.e. recording) rain gages in Boston at Logan Airport; in Milton at the Blue Hill Observatory; and at the site of the former South Weymouth Naval Air Station. Other gages near the watershed are cooperative weather stations which record data on a daily basis. Cooperative stations, also referred to as non-recording stations, in or near the watershed include: Plymouth-Kingston, and Pembroke (no longer exists as of 1989).[4] **Table 3-1** lists the stations of interest in this study along with their period of record. The approximate location of the stations are presented in **Figure 3-2**. Massachusetts DEM also receives data from rain gages at Pembroke (Silver Lake) and Plymouth.

3.22 Temperature

Detailed temperature information is most readily available for the recording climate gage in Boston/Logan Airport. Monthly average temperatures in Boston range from 73.5°F in July to 28.6°F in January. Monthly average maximum and minimum temperatures in Boston peak at 81.8°F in July and 21.6°F in January.[5] The temperature range in Kingston averages 71.0°F in July to 26.5°F in January.

3.23 Precipitation

The only NWS precipitation gage which currently exists within the Jones River watershed area is Plymouth-Kingston. Mean annual and monthly precipitation for the stations in and around the watershed are presented in **Table 3-2**. Stations located closest to the watershed in Plymouth-Kingston and Pembroke have similar mean annual and monthly precipitation. The mean annual precipitation using these gages, including the water equivalent of snowfall, is 47.3 inches, indicative of the mean annual precipitation for the Jones River watershed.[6] Typical monthly mean values for the Plymouth-Kingston gage are lowest in July at 3.14 inches and highest in December at 4.47 inches. The mean annual precipitation at the Pembroke (1948 to 1997) gage is 48.8 inches, which is quite similar to the Plymouth-Kingston gage.

3.24 Evapotranspiration

Monthly average temperature records were obtained for the City of Boston to

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[4] United States Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Data Center, "Cooperative Summary of the Day," Volume 16, June, 1995.

[5] United States Department of Commerce, National Weather Service, "Normals, Means, and Extremes: Boston, MA" http://tgsv5.nws.noaa.gov/er/box/climate/BOSTON__MA_____.html

[6] National Climatic Data Center, U.S. Monthly Precipitation for Cooperative and NWS Sites, July, 1999.

quantify evapotranspiration in the Jones River watershed using the Thornthwaite equation[7]. The process of evapotranspiration is difficult to measure directly and is commonly computed as the remainder after all other gains and losses have been calculated (i.e., Precipitation minus Total Runoff). The Thornthwaite equation relates evapotranspiration (ET), on a monthly basis, to air temperature and daylight duration. Theoretical mean monthly and annual evapotranspiration are presented in **Table 3-3**. The mean annual evapotranspiration is computed to be about 26.5 inches. Monthly evapotranspiration values peak in July at 5.49 inches and are negligible when the average daily temperatures are below freezing in January and February. Thornthwaite calculations are presented in **Appendix C**.

The ET rates listed in **Table 3-3** are potential evapotranspiration rates. The amount of evapotranspiration which actually occurs is dependent upon the amount of water which falls as precipitation, and is available for uptake in the root zone. For example, the month of July has a potential evapotranspiration of 5.49 inches. However, if the amount of precipitation is only 1.0 inch and there is no significant water in the root zone, the actual ET will be much less than 5.49. However, simple evaporation from open water surfaces will continue as long as a water source remains. It should be noted that in June, July, and August, potential ET is typically greater than actual precipitation; thus, minimal recharge to groundwater during these months is expected.

3.30 SURFACE WATER HYDROLOGY

The Jones River watershed contains several streams and rivers including the Jones River, Jones River Brook, Pine Brook, Halls Brook, Smelt Brook, and Furnace Brook. There are several ponds which are natural or have been formed by human-made impoundments on these streams including Silver Lake (a natural Great Pond) at the headwaters of the Jones River; Wapping Pond and the Elm Street impoundment on the Jones River; and Upper and Lower Chandler Pond on Pine Brook. Estimates of the amount of water flowing into and out of these streams and ponds will form a major portion of the hydrologic description of the watershed. These estimates were conducted as part of the inflow/outflow analysis, utilizing the existing streamflow data base information discussed below.

Streamflow records are the basis for estimation of water-supply potential and are used to estimate mean annual flows, frequency and duration of flows, and the magnitude and frequency of floods. The amount of flow in a stream depends on the size and topography of the upstream drainage area, precipitation, evapotranspiration, storage of water, surficial geology, and the influence of development and diversions on the system. A summary of the existing flow data for the Jones River is contained in **Appendix D**.

The USGS operates a continuous stream gage within the Jones River watershed below the Elm Street Dam. The gage (USGS ID 01105870) covers a drainage area of 19.8 mi^2, including the 4.1 mi^2 Silver Lake watershed. Records at the gage are generally considered good by the USGS; however, flow is regulated by the Elm Street Dam, and influenced by

[7] Chow, Ven Te, Ed. Handbook of Applied Hydrology. McGraw Hill, NYC. 1964.

the operations at Silver Lake and occasionally by tidal surges.[8] In addition to the continuous gage, a low flow, partial record (LFPR) gage was established by the USGS on the Jones River Brook to estimate flow-duration and low flow frequency statistics. This low-flow, partial record stream gage, which has a contributing drainage area of about 4.74 mi^2, was installed at the culvert on West Street on the Jones River Brook during the summers of 1983, 1984, 1993, and 1994.[9] **Figure 3-6** shows the location of these two stream gages in the watershed.

Flow-duration curves depict the average percentage of time that specific flowrates are equaled or exceeded at a particular site. These curves are useful for better understanding the nature of the streamflow in a particular river. For example, 'flat'-sloped flow duration curves often indicate relatively little variability in flows, as compared to a site with a steep flow duration curve. The information the curves provide is important when assessing the variability of flows predicted in the inflow/outflow analysis. **Table 3-4a and b** and **Figure 3-3** contain the streamflow statistics describing the flow-duration curve for the Jones River Brook, as calculated by the USGS using data from the LFPR gage as well as GZA-developed flow-duration characteristics for the Jones River at Elm Street using USGS methodology. This information was developed using the USGS computer programs ANNIE and SWSTAT. The data is provided on a drainage-area unitized basis (i.e., cfsm). The results for the Jones River gage at Elm Street indicate a 50-percent flow duration value of about 1.3 cfsm. The flow-duration curve is fairly flat, due to prevalent stratified drift in the watershed enabling a fairly constant discharge of groundwater to the river system (USGS, 1991).

The USGS obtained additional low flow measurements throughout the Southeast Coastal Basin in the summers of 1986 and 1987 as part of a 1991 published study.[10] One of the objectives of the study was to predict long-term aquifer yield (see Section 3.45), by incorporating flow-duration data with other field measurements and physical watershed characteristics. Several of the measurements were taken by the USGS several days after measurable rainfall and were considered to be representative of groundwater discharge (baseflow). Baseflow data from the study for streams within the Jones River watershed is presented in **Table 3-5**. The results of the flow measurements indicate variation in the typical magnitude of baseflow on a cfsm basis. In general, the data indicates the baseflows in the Jones River Brook, Pine Brook, Fountainhead Brook, and Upper Jones River are appreciably lower than those in the Furnace Brook, Smelt Brook, and Halls Brook subbasins. Surficial geology by subbasin (**Table 2-4**) does not indicate substantial differences in the amount of stratified drift to account for the baseflow variation. The variation may be due to any number of factors, including aquifer characteristics, and upstream flow regulation. In fact, as evident in **Figure 3-4**, a larger extent of higher yield

[8] USGS, "Water Resources Data Massachusetts and Rhode Island, Water Year 1999" Water-Data Report MA-RI-99-1, Northborough, MA 2000.
[9] USGS, "Streamflow Measurements, Basin Characteristics, and Streamflow Statistics for Low-Flow Partial Record Stations Operated in Massachusetts from 1989 Through 1996" Northborough, MA, 1999.
[10] USGS, "Yields and Water Quality of Stratified-Drift Aquifers in the Southeast Coastal Basin, Cohasset to Kingston, Massachusetts," 1991.

aquifers underlie the baseflow-rich subbasins.

Other limited-duration stream gaging efforts have been made as part of previous studies and by the Jones River Watershed Association (JRWA). The Kingston Water Department (KWD) monitors the stage (i.e., height/depth) of Smelt Brook. These measurements are limited to stage recordings at various sites throughout the basin and have not been related to actual flow rates. Therefore, this data is limited for use in calibrating or verifying a hydrologic model.

The City of Brockton monitors diversion flows into and out of Silver Lake. This data is provided in **Appendix E**. A summary of the diversion/operational practices is provided in Section 4.10.

The 1981 DEQE Water Quality Data Report for the South Coastal Basin, Jones River involved limited flow measurements at two sites along the Jones River and Jones River Brook. Measurements were made in June and August and varied from 0.33 cfs in Jones River at Grove Street (6/24/1981) to 2.04 cfs in Jones River Brook at West Street (6/24/1981).

More extensive flow measurements throughout the watershed were made as part of the 1989 Teal Ltd. Report. The flow measurement effort entailed the installation of staff gages (meter sticks) at 16 sites in the watershed. These gages were then monitored by local residents. In-stream flows were also measured by Teal Ltd. on six occasions from May, 1988 to July, 1989. The flow measurement methodology and the development of graphically presented flowrates from the staff gages is not adequately described in the study, in GZA's opinion. Readings from the staff gage near the Elm Street Dam were compared to the USGS stream gage reported data and showed good correlation. The Teal Study also reports groundwater contributions to baseflow, apparently based on work performed by David G. Johnson as described in an out-of-print 1986 article in "Civil Engineering Practice," coupled with Teal flow measurements. Again, the methods of estimating baseflow contributions to total streamflow are not described in the study. The general conclusions in the study include the identification of Pine Brook, Jones River Brook (Barrows Brook), and the Upper Jones River as the most significant contributors to total flow in the Jones River. Data from the report also suggests Furnace Brook can also be a significant contributor, particularly during the summer months. Given the lack of documentation of flow and base flow development methodology, coupled with the short approximately 1-year duration of gage observation, streamflow and baseflow data contained in the study is inappropriate for use in calibrating the planned water budget model, in our opinion.

3.40 GROUNDWATER HYDROLOGY

An important part of the hydrologic cycle occurs in the subsurface as groundwater moves through the saturated zone from areas of recharge to areas of discharge (baseflow). Proper water resources development and management requires an understanding of: the extent and hydrologic characteristics of subsurface materials, the amount of water available, and the groundwater flow system and its relation to the overall hydrologic cycle. Consideration and development of baseflow/recharge estimates are a key component of GZA's water budget model. The physical characteristics of the underlying aquifers in the Jones River watershed and the baseflows they contribute were estimated in the model based on runoff/baseflow separation techniques as applied to streamflow data (discussed above) and the groundwater hydrology summarized below.

3.41 Aquifer Descriptions

The Kingston Coastal aquifers include extensive outwash and stratified drift deposits. In southern Kingston, the stratified drift deposits grade into the thick outwash sheets that cover Plymouth and Cape Cod. These outwash plains consist of flat-lying to gently dipping beds of sand and gravel that were deposited by glacial-meltwater streams. These aquifers are among the best in the area, and are capable of yielding 300 gallons per minute or more in individual wells (USGS, Persky, 1991). Sand and gravel make up about 84 percent of the basin surficial geology.

There are several high-yield aquifers in the watershed along the Jones River, Pine Brook, Halls Brook, Furnace Brook, and the Smelt Pond/Kingston Coastal Area (**Figure 3-4**). However, the aquifer materials located in Kingston often underlie more than one surface-draining area (i.e., subbasin). For example, the Upper Jones River (see **Figure 2-3** and **Figure 3-4**) aquifer includes not only part of the Jones River Valley, but also the basins of Fountainhead Brook and two unnamed tributaries. The Halls Brook aquifer includes the materials along the Mile Brook and Bassett Brook tributaries. In the northwestern corner of the watershed, there is an additional high-yield aquifer underneath both Tubbs Meadow Brook and Herring Brook (Silver Lake subbasin). Therefore, the surface-water and ground-water divides do not always coincide; this is particularly the case when pumping occurs near the surface water divide. For example, the USGS reports that along Fountainhead Brook in the Jones River subbasin, ground-water flows beneath the surface-water divide and recharges the part of the aquifer pumped by the Town of Kingston's South Street well, which is actually in the Furnace Brook sub-basin. Nonetheless, the standard hydrologic assumption is to equate groundwater and surface water boundaries, as was done in the above referenced USGS study.

A Zone II delineation (**Figure 3-4**) is typically required by the DEP for public ground water withdrawals of 100,000 gpd or more. Zone II studies estimate the zone of contribution (recharge area) for a well pumping at its rated capacity for 180 days without recharge. Conceptual Zone II delineations have been performed for the majority of the public water supply wells in the basin. Due to the complexities of the source aquifers as described above, many of the Zone IIs encompass groups of wells instead of individual wells. Estimates of groundwater divides within the same aquifer system containing multiple pumping wells include some amount of uncertainty. In the absence of approved Zone II delineations, Interim Wellhead Protection Areas (IWPA) are adopted as the primary, protected recharge area for groundwater sources. The IWPA is not a reflection of the extent or shape of the actual aquifer. An IWPA is circular and its radius is proportional to the well pumping rate and ranges from a minimum of 400 feet and a maximum of ½ mile.

Bedrock Aquifers

Bedrock formations can also store and transmit ground water. In this case, water is stored within the fractures and joints of the bedrock. The yield from bedrock wells depends on the number, size, and interconnections of the joints and fractures in the rock. The quantity of water which can be withdrawn from bedrock on a regional basis is governed by the amount of recharge from precipitation and the ability of the bedrock aquifer to transmit water. A study of the entire Southeast Coastal Basin (from Cohasset to Kingston) completed in 1993 by the USGS examined yields of 133 bedrock wells throughout the basin[11]. The median yield of the wells was 6 gallons per minute (gpm). Therefore, such wells may commonly be adequate supplies of water for household use, but generally have insufficient yield for public water supply.

3.42 Saturated Thickness and Transmissivity

General aquifer information is readily available in USGS publications including "Geohydrology and Simulated Ground-Water Flow, Plymouth-Carver Aquifer," WRI 90-4204 and "Yields and Water Quality of Stratified-Drift Aquifers in the Southeast Coastal Basin, " WRI 91-4112 as well as the Zone II Delineation Studies performed for the public water supply wells in the Towns of Duxbury and Kingston. The saturated thickness of the aquifer ranges from 40 feet in the vicinity of Lower Chandler Pond to as much as 100 feet in the northern fringe of the Plymouth-Carver aquifer. Typical transmissivities range from about 20,000 to 75,000 gpd/ft throughout the aquifer.

3.43 Gradients and Flow Patterns

In general, without considering the effects of groundwater pumping by the wells in the Jones watershed, the groundwater flow pattern is expected to generally proceed from topographic highs to low and discharge into rivers and streams. The hydraulic gradient can be thought of as the groundwater equivalent of stream slope.

Based on previous studies, it is evident that groundwater flow does not always correspond to subbasin surface water boundaries[12]. Groundwater elevation contour maps from these studies are provided in **Appendix F**. There are indications that the groundwater divide in the northern portion of the Silver Lake subbasin, between Herring Brook (in the North River Watershed) and the headwaters of Tubbs Meadow Brook may be slightly

[11] USGS, "Yields and Water Quality of Stratified-Drift Aquifers in the Southeast Coastal Basin, Cohasset to Kingston, Massachusetts", 1993.
[12] Pilgrim Resource Conservation and Development Area Council, "Silver Lake Hydrogeologic and Land Use Study," March, 1988.

south of the surface watershed divide. Groundwater contours around Silver Lake indicate groundwater inflow from the west, north, and east, and outflow in a southeasterly direction, just south of the bedrock outcrop adjacent to Forge Pond. This may indicate a general inflow of groundwater from the Forge Pond area, while a natural outflow occurs near the wetland area south of Forge Pond (assuming a Lake level of 47 ft). Lowering the elevation of Silver Lake would potentially affect the flow of groundwater, inducing infiltration from additional areas east and southeast of the Lake, depending on its water surface elevation.

Other instances of groundwater flow patterns diverging from surface watershed boundaries exist in the southeastern portion of the watershed at the Furnace Brook and Smelt Brook subbasins and to a much lesser extent at the northern subbasin boundary in the Dead Swamp area of the Halls Brook subbasin. Groundwater elevation data from the USGS indicates the groundwater divide in the southeastern portion of the watershed follows the Plymouth-Kingston border from Kingston Bay inland to Lyon Pond (north of the Sacred Heart School) before re-establishing itself near the vicinity of the surface watershed divide by the Plympton-Kingston town line. Although the groundwater flow may be in a general south-to-north direction from the Plymouth-Kingston town line to Smelt Brook, groundwater outflow from beyond the Smelt Brook or Furnace Brook subbasins would likely appear in surface waters which are contributory to the South Coastal watershed of Plymouth. The available groundwater elevation data also suggests there is enough distinction between the groundwater gradients of Furnace Brook and Smelt Brook to separate their respective subbasins from each other (i.e., area of groundwater contribution to each stream is nearly distinct).

3.44 Water Level Records

Groundwater elevations typically fluctuate seasonally, rising during periods of recharge from late autumn to early spring, and falling during late spring through early autumn. The amount of fluctuation is, in part, dependent on the geology of a particular site—groundwater levels tend to rise more dramatically in areas of limited hydraulic conductivity, such as till, than in areas of more favorable hydraulic conductivity, such as gravel.

Approximate groundwater elevations and flow patterns are discussed in Section 3.43. The USGS does not maintain any observation wells in the watershed. The Town of Duxbury monitors groundwater levels in the South River Basin, northeast of the watershed. The Massachusetts Office of Coastal Zone Management (CZM) is currently planning an index well program in the South Shore which will reportedly contain an observation well in Kingston.

3.45 Groundwater Outflows (Baseflows)

The baseflow of the streams of the Jones River watershed is supplied by groundwater released from aquifer storage. Groundwater outflow is difficult to directly measure, except at well-defined springs. As such, groundwater outflow is generally estimated by measuring streamflow before or significantly after rain events. When rain or other water infiltrates into the soil, particularly in the areas of stratified drift, it serves to recharge the groundwater aquifers. Because most of these aquifers are unconfined, additional water is stored, causing a rise in the water table. When the water table intersects the ground surface at a low area such as a streambed, water can re-emerge to become baseflow to the stream. Over the long term and under natural conditions, it can be assumed that the overall quantity of groundwater stored in the aquifers is relatively constant. Water which infiltrates (i.e. recharges) into the watershed subsurface eventually re-surfaces, either as outflow to streams or direct outflow to the sea.

Pumping of groundwater and impervious areas which restrict recharge can affect the hydrologic cycle. As water is extracted from groundwater aquifers (and the water table is lowered by pumping), the amount of groundwater outflow to rivers and surface water features can be reduced, stopped, or even reversed. When wells are pumped, water from streams begin to recharge the groundwater, a situation known as “induced infiltration” is said to exist. The quantification of streamflow depletion due to pumping wells was addressed via the Jenkins Method, as discussed in Section 5.0.

Impervious areas, especially large-scale, connected impervious areas, can also limit infiltration and thus decrease baseflows. In the Jones River watershed, the land use is predominantly wooded, which is not generally indicative of the highly developed, connected impervious areas which significantly alter baseflow. The estimated total of 7.1 percent impervious area of the watershed (**Table 2-5b**) would seem to indicate impervious areas are not a major factor in reducing baseflows. Further, much of the impervious area is concentrated in the relatively highly developed Tidal subbasin (15 percent impervious) which, due to its tidal nature, does not significantly contribute to overall fresh water flow in the river. Therefore, imperviousness within the watershed is not considered to significantly impact the overall water budget of the basin.

<u>3.46 Aquifer Yield</u>

The 1991 USGS aquifer yield study, previously discussed in Section 3.41, estimated long-term aquifer yields based on a series of baseflow measurements in and around the South Coastal Basin. The study presented yield-duration tables, which provide estimates of availability on a percent-exceedence basis. Portions of the table are replicated in **Table 3-6.** The USGS methodology does not specifically address the maintenance of particular in-stream flows or aquatic habitat. However, the study provides insight into the contribution and characteristics of the flows emanating from the Jones River and some of its tributaries.

The report elaborates on the significance of the duration statistic: “In theory, if [the 80-percent yield] were pumped from the aquifer and not returned, during the 20 percent of the time when the lowest flows occur, the stream would be dry and pumping would deplete the ground-water storage of the aquifer to make up the deficit.”[13] The methodology

[13] USGS, “Yields and Water Quality of Stratified-Drift Aquifers in the Southeast Coastal Basin, Cohasset to

assumes withdrawals during low-flow periods are made at the expense of base flows and therefore to prevent streams from drying up for any given flow duration, the volume withdrawn must be lower than yield presented.

For example, Halls Brook has an available yield of 2.7 MGD at an 80 percent duration. To preserve flow in the stream of 1.8 MGD (as an example) at the 80-percent flow duration, the amount of pumping would be limited to 0.9 MGD (2.7 MGD less 1.8 MGD). Problematic in this regard is the nature of the flow-duration curve in the basin. Given the amount of stratified drift and flat nature of the flow-duration curve as discussed earlier, base flows at the 80-percent duration may not significantly vary from the 95-percent duration. As a result, much of the available yield would be precluded from use to maintain the 95-percent duration flow. Maintenance of minimum stream flows is therefore a balance of aquatic habitat needs and water supply needs, dictated by basin stakeholders and policy-makers.

The report also notes that the coastal aquifers do not solely discharge to main-stem streams, instead outflowing directly to the ocean or small coastal streams. This is especially the case in the "Kingston Coastal" basin, which is a conglomerate of the Smelt Brook and Tidal subbasins, and also a factor in the Halls Brook available yield. The end point of the Upper Jones River aquifer, near the confluence of Fountainhead Brook, is situated in materials with reportedly low transmissivities, which also would preclude the utilization of its reported aquifer yield.

3.50 WATER QUALITY

Groundwater in the Southeast Coastal basin is reported to be suitable for most uses (USGS, 1993). Typical problems with groundwater quality for coastal basins in southeastern Massachusetts include naturally occurring saltwater intrusion, iron and manganese, and color. Land use may also provide additional sources of groundwater quality problems, such as landfill leachate/sewage disposal or chemical contamination.

The 1991 USGS study investigated the water quality of the stratified drift aquifers in the region from Cohasset to Kingston, Massachusetts. A total of 19 wells and surface water from the Jones River were sampled and analyzed for nutrients, selected trace metals, and phenols. About 9 of the wells were in the Jones River Watershed. Results of the analysis indicated that naturally occurring iron and manganese were the major constituents of concern. Roughly half of the wells sampled and the Jones River had levels of iron and manganese greater than EPA secondary drinking-water standards. Apparently, this has been an historic problem with area water supplies, as wells have gone offline or been relegated to a backup/emergency source in Duxbury and Scituate due to exceedingly high levels of iron, manganese, color, and/or chloride. These minerals can cause aesthetic problems in public water supplies (rust, staining of laundry, taste, and odor; they can also precipitate and clog well screens).

Kingston, Massachusetts", 1993.

Surface water sampling in the Jones River watershed was also performed as part of the 1989 Teal Ltd. "Jones River Study." The study investigated numerous classes of water quality parameters: coliform, nutrients, and metals/volatiles/herbicides/pesticides/PCBs. Results of sampling efforts during August and November of 1988 indicated that coliform levels were elevated during August low-flow conditions and were lower during higher-flow conditions in November. There were no indications that volatiles, PCBs, herbicides, or pesticides were present during the sampling rounds.

Sediment analyses from the impoundments at Wapping Road and Elm Street did not contain unacceptable concentrations of metals. Nutrient analyses for samples taken in October and November indicated elevated levels of phosphorous and ammonia, likely due to bog activities (bog nutrient cycling) and/or the normal processes of plant decomposition occurring in surrounding wetlands. The sampling, however, found that the non-tidal portion of the river contained nitrogen and phosphorous levels which were not favorable for excess eutrophication. This observation would seem to be contrary to existing conditions documented in the 1995 Jones River Shoreline Survey (Jones River Watershed Association) which observed eutrophic conditions in the upper portions of the Jones River, particularly above Route 106.

The 1995 Jones River Shoreline Survey also reported concerns in the tidal portions of the watershed regarding the misoperation of septic systems. Malfunctioning septic systems have been identified as suspects in elevated contaminant levels in former shell fishing beds in Kingston. Fecal coliform sampling results from the Survey in the Tidal portions of the watershed ranged from 500 counts per 100 mL to 36,000 counts per 100 mL. The shell fishing limit is 14 counts per 100 mL. Action has been taken to remedy the situation, as the relatively densely populated tidal portion of the watershed is serviced by sanitary sewer and a wastewater treatment plant (**Figure 3-5**).

3.60 GZA STREAM FLOW MEASUREMENTS

GZA visited the watershed on September 18, 2001, January 29, 2002 and April 3, 2002 to take flow measurements at eleven locations along the Jones River and its tributaries during periods of low, normal, and high flow. Flow measurement locations were chosen to provide a wide geographic distribution, and based on proximity to confluences and accessibility.

Flows were measured using a FloMate Flow Meter which records velocity. The primary technique that was utilized was the "Six-Tenths Depth Method" as described in the USGS paper "Measurement and Computation of Streamflow."[14] Velocity measurements were taken at stations along the stream cross section at 0.6 x depth. The 0.6 x depth velocity is used as the mean velocity in the vertical. The stream was divided into multiple subsections based on the width of the stream and local features. Vertical velocity readings were taken

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[14] Rantz, S.E. et. al. United States Department of the Interior, United States Geological Survey. "Measurement and Computation of Streamflow: Volume 1. Measurement of Stage and Discharge" Geological Survey Water-Supply Paper 2175, 1982.

at each subsection. Depths and widths were recorded at each subsection. Flow rates were then calculated by multiplying the mean vertical velocity by the cross-sectional area of the subsection and summing across the stream. Flow data is presented in **Table 3-7** and the sampling locations are plotted in **Figure 3-6**.

The September measurements were made in an effort to obtain data which would be generally representative of low flow conditions. Precipitation prior to the September flow measurement was below normal (0.46 inches in September prior to the 18th) at the Plymouth climate station, and hydrologic conditions, in general, were drier than normal. The reported flow at the Jones River USGS gage at Elm Street was 5 cfs, which is expected to be exceeded about 99 percent of the time (Figure 3-3). Forge Pond Dam was not spilling at the time of GZA's field visit in September, thus, the contributory drainage area to Silver Lake was not adding flow to the Jones River. GZA flow measurements ranged from a high of 3.9 cfs at Smelt Brook (1.5 cfsm) to a low of 0.0 cfs at the Jones River below Forge Pond Dam. Stream flow at Pine Brook at Grove Street was measured at 0.3 cfs (less than 0.1 cfsm) and at Jones River Brook at West Street at 0.6 cfs (about 0.1 cfsm). Halls Brook near Route 3A and Furnace Brook near Route 80 were flowing at about 0.5 cfsm (2.0 cfs and 0.7 cfs, respectively).

Typical January flows are expected to be representative of normal to high flow conditions. However, precipitation as measured at the Plymouth climate station, of previous months were drier than normal (3.25 inches in January, 3.48 inches in December, 1.16 inches in November, etc.) and drier than normal hydrologic conditions were prevalent in the region, in general. Forge Pond Dam was again not spilling at the time of the January field visit. The flow at the Jones River USGS gage at Elm Street was reported to be 14 cfs, which is expected to be exceeded about 76 percent of the time (Figure 3-3). Measured flows ranged from a high of 7.8 cfs at Jones River Brook at West Street (1.6 cfsm) to a low of 0.0 cfs at the Jones River below Forge Pond Dam.

Flows in April are typically considered representative of average annual high flow conditions (not extreme flood flows). Typically, spring rainfall and snowmelt contribute to increased streamflow during March and April. However, the below average snowfall and precipitation may have produced less than the average annual high flow for April, despite the 1.1 inches of rain which fell two days prior to the flow measurement. The flow at the Jones River USGS gage at Elm Street was reported to be 57 cfs, which is expected to be exceeded about 18 percent of the time (Figure 3-3). Forge Pond Dam was again not spilling at the time of the April field visit. However, there was measurable stream flow in the Jones River (about 0.1 cfs) only about 100 ft below Forge Pond Dam as a result of groundwater outflow contribution, combined with seepage through the dam. Measured flows ranged from a high of 19.7 cfs at Halls Brook near Route 3A (3.7 cfsm) to a low of 0.0 cfs at the Jones River immediately below Forge Pond Dam. Smelt Brook at Route 3A (8.5 cfs or 3.2 cfsm), Jones River Brook at West Street (17.6 cfs or 3.7 cfsm), and Pine Brook (8.1 cfs or 1.7 cfsm) each had relatively higher flows than previous visits. Furnace Brook near Route 80 was measured at 1.3 cfs (about 1 cfsm), which was approximately the same flow rate observed in January. This measurement may have been affected by potential operations upstream fish ladders / impoundments, which GZA did not observe.

Although the flow measurements are useful for the development of rating curves for future flow monitoring and provide information on the flow rates of the watershed on a particular day, the usefulness of the measurements for use in calibrating or verifying the inflow / outflow analysis is limited. Instantaneous flow measurements, such as those taken by GZA for this project, reflect “snap-shots” of watershed hydrology and do not necessarily represent average monthly stream flow or base flow, which is estimated in the inflow / outflow analysis discussed in Section 5.00.

4.00 WATER SUPPLY AND USE

The Commonwealth of Massachusetts passed the Water Management Act (WMA, M.G.L. c.216) to control and allocate the water resources in the state and to ensure adequate resources for the present and future. In January, 1988, all water users had the opportunity to register their historic water use for the period 1981 to 1985. This registered an average day water use over that period that, if confirmed and approved by the state, became the "grandfathered" quantity allotted to the user. After the registration phase of the Act, the permitting process began in 1988. A permit is required if an existing or new user intends to or is using more than 100,000 gpd over the previously registered amount. The registered and permitted withdrawal volumes for all public water suppliers within the Jones River watershed are shown in **Table 4-1** along with current water supply withdrawal points. Copies of pertinent legislative acts, registration and permit data are contained in **Appendix G.** **Appendix H** provides a database of Water Management Act information pertaining to the South Coastal Basin (provided by Duane LeVangie of the DEP).

Additionally, the transfer of water from one river basin to another within Massachusetts is regulated via the Interbasin Transfer Act (ITA) of 1983. The ITA is administered by the Water Resources Commission (WRC) with technical oversight provided by the DEM-OWR. There is no threshold that triggers regulation—any interbasin transfer developed after 1983 must be reviewed at some level. Transfers developed prior to 1983 (i.e., the City of Brockton Silver Lake System) are not subject to approval by the WRC.

GZA inventoried registered and permitted water withdrawals as part of this study in 2001. The registered and permitted supplies included predominantly municipal or agricultural water supply withdrawals. Registered relatively minor users of water (less than 0.2 MGD) included cranberry bog owners, schools, and campgrounds. There were no permitted industrial users, private water suppliers, nor golf courses found in the DEP database or files.

4.10 PUBLIC WATER SUPPLY SOURCES

To understand the overall water budget and the anthropogenic impacts which may affect the hydrologic cycle, the major water supply withdrawals in the watershed must be identified and quantified. Drinking water suppliers often own and operate large-scale water withdrawals that may influence the water budget through diversions and withdrawals from streams, ponds, and aquifers. There are four major water suppliers which withdraw water from the watershed: the City of Brockton and the Towns of Duxbury, Kingston, and Pembroke.

Table 4-2 lists the major registered and permitted municipal water supply wells of the Jones River watershed and their physical characteristics. **Figure 3-4** shows registered and permitted well locations, DEP-Approved Zone II delineations and interim wellhead protection areas.

4.11 City of Brockton Water Supply System

The City of Brockton is located in the Taunton River Basin, which borders the western side of the Jones River watershed. In 1899, Legislation was passed which allowed the City of Brockton to divert water from Silver Lake to meet its water supply needs. The 1899 Act also provided that Brockton shall supply water to any town named in the Act, including Plympton, Halifax, Kingston, Pembroke, Whitman and Hanson. Of these towns, Whitman and Hanson requested water from Brockton.

In 1964, legislation was passed that authorized the diversion of flow from Furnace Pond, in Pembroke, and from Monponsett Pond, in Halifax and Hanson, to Silver Lake from October to May, inclusive. The 1964 Act, as amended in 1981, provided restrictions regarding the diversions, including:

- minimum downstream flow requirements of 300,000 gallons per day (gpd) from Furnace Pond to Herring Brook and 900,000 gpd from Monponsett Pond to Stump Brook (except in case of emergency when less water may be discharged if ordered by the Department of Public Health);
- at all times, sufficient flow shall pass downstream when water is being diverted to allow for the passage of herring;
- no withdrawals below minimum water surface elevations of 56.0 ft (NGVD) in Furnace Pond and 52.0 ft in Monponsett Pond.

Brockton also has sources within the Taunton River Basin, the Avon Reservoir in the Town of Avon and an emergency supply well on Hubbard Avenue within Brockton city limits.

According to the 2000 Public Water Supply Annual Statistical Report, Brockton withdrew an average of 10.7 MGD from its combined sources. Of this total withdrawal, an average of 10.25 MGD was withdrawn from Silver Lake.

Brockton supplies the Town of Whitman with 100 percent of its public water supply. In 2000, Brockton supplied Whitman with 0.93 MGD. Additionally, a few areas within the Town of Hanson are directly connected to the Brockton system, and Brockton provides an emergency back-up supply in case of failure within the Hanson water supply system. In 2000, Brockton supplied Hanson with 0.04 MGD. A very small amount of water, 0.11 MG, was also sold to the Town of Halifax during 2000. Therefore, Brockton’s average net water consumption in 2000 was 9.71 MGD

Under the Water Management Act, Brockton is registered to withdraw 11.11 MGD from Silver Lake (including the diversions from Furnace and Monponsett Ponds), and 0.04 MGD from the Hubbard Avenue well, and is permitted to withdraw 0.83 MGD from the Avon Reservoir, for a total authorized withdrawal of 11.98 MGD. However, Brockton’s withdrawals are currently further restricted by an Administrative Consent Order issued by the Department of Environmental Protection which limits Brockton's total withdrawal to 110 percent of the system safe yield, or 11.3 MGD.

The City of Brockton maintains records regarding flow diversions to and withdrawals from Silver Lake. Diversions from Monponsett Pond are considerable, often more than 25 MGD. Diversions from Furnace Pond are relatively lower, ranging from 0 to 10 MGD. The data is summarized in **Table 4-3**, **Figures 4-1 and 4-2** as well as **Appendix E**. The level of Silver Lake fluctuates seasonally, reaching a minimum of two to six feet below the "full" level of the Lake according to the City of Brockton data (from 1996 to 2000) in autumn and reaching its maximum at or inches above the Forge Pond Dam spillway in the late winter or early spring. Once the Lake level dips below the crest of the Forge Pond Dam spillway, contributing flow to the Upper Jones River is limited to seepage through the spillway stoplogs and the dam itself.

4.12 Town of Kingston Water Supply System

According to the 2000 Public Water Supply Annual Statistical Report, the Town of Kingston withdrew an average about 1.3 MGD from five active water supply sources. The entirety of Kingston's supply comes from groundwater via wells at Soule's Pond, South Street, Millgate Road, Grassy Hole (Independence Mall Road), and Trackle Pond (Route 80). Kingston also owns an inactive well at Winthrop Street. Trackle Pond well is the lone permitted (as opposed to registered) source owned by Kingston. The permit is staggered to allow for increasing withdrawals:

To 8/31/2000:	0.51 MGD annually
9/1/2000 to 8/31/2005:	0.54 MGD annually
9/1/2005 to 8/31/2010:	0.57 MGD annually

The remaining wells are registered for a total of 0.99 MGD. Therefore, Kingston's registered and permitted withdrawals will range from 1.53 MGD as of August 31, 2000 to 1.56 MGD as of September 1, 2005.

Soule's Pond, South Street, Millgate Road, Grassy Hole (Independence Mall Road), Winthrop Street (inactive) and Trackle Pond (Route 80) wells are owned and operated by the Town of Kingston. Three of the wells, Soule's Pond, Millgate Road, and South Street, are located in the unconfined, high yield, stratified drift aquifer which underlies the Furnace Brook subbasin. These wells have DEP-listed pumping capacities ranging from 250 to 750 gpm and are located at depths of 65 to 90 feet. The Grassy Hole well is located beneath the Smelt Brook subbasin between Smelt Pond and Route 3 (near the Independence Mall). It has a pumping capacity of 800 gpm and is 93 feet deep. The inactive Winthrop Street well is in the Halls Brook subbasin and can pump up to 400 gpm.

The Trackle Pond well, which was permitted in 1999, lies beneath the extreme southern end of the Furnace Brook subbasin. Although the Trackle Pond well is located within the bounds of the Jones River watershed, the majority of the Zone II delineation for the well (88 percent) lies outside of the basin surface water divide. The DEP permit, issued in July, 1999, states: “Please note that the maximum daily withdrawal volume from the Trackle Pond well is less than the rate which was approved at the time of the Zone II approval for this well. This is due the [sic] well’s location inside the Jones River sub-basin. Because of the Department’s decision not to authorize additional withdrawals in the Jones River sub-basin, only that portion of the withdrawal which comes from outsid ethe sub-basin boundary may be permitted.” On this basis, the DEP has permitted 88 percent of the previously approved withdrawal rate for the well (the 88 percent is reflected in the numbers above). The DEP also imposed a number of special conditions with the approval of the well in 1999, including:

- Monitoring of the potential vernal pool adjacent to the Trackle Pond Well is required on an annual basis.
- Adoption of a Water Use Restriction Bylaw within two years of the issuance of the permit.
- Conduct a build-out analysis for the Town of Kingston and analyze the ability of the system to meet long term (20 year) demand without increasing withdrawals from the Jones River Sub-basin.
- Develop a groundwater observation plan to assess impacts to Carter Cranberry’s registered withdrawal point at Indian Pond attributable to the permitted withdrawal.
- Develop a water management plan to mitigate against potential impacts.
- Monitor daily streamflows in the Jones River at the USGS gage at Elm Street. To implement this daily monitoring, the Department requires that the gage be upgraded to include a Satellite Data Collection Platform within one year of the date of issuance of this permit.
- The Department requires that a notice be published in a local daily paper requesting that Kingston Water Department customers conserve water when streamflow in the Jones River falls to 8.0 cfs at the USGS gage on Elm Street for 5 consecutive days.

The Town of Kingston is in the midst of responding to the above special conditions[15]. The Satellite Data Collection Platform has been purchased and installed. The Town is also in the process of developing a groundwater observation plan. DEP will reportedly review the Town’s progress on the special conditions at the scheduled 5-year review of the permit.

4.13 Town of Pembroke Water Supply System

The Town of Pembroke operates four wells in and around the Jones River Watershed. The regulated withdrawals are split into registered and permitted volumes. The registered amount is 0.99 MGD and the permitted amount is as follows:

9/1/2000 to 8/31/2005:	0.24 MGD annually
9/1/2005 to 8/31/2010:	0.27 MGD annually

Therefore, the total registered and permitted volume of withdrawals by the Town of

[15] Matthew Darsch, Kingston Water Department, Personal Communication.

Pembroke are 1.23 MGD until August 31, 2005, and on September 1, 2005 they increase to 1.26 MGD. Only one of the wells (GP#3-School Street) is located within the surface watershed of the Jones River (Silver Lake subbasin). The remaining wells (GP#1-Hobomock Street, GP#2-Center Street, and GP#4-Sandy Lane) are outside the boundaries of the watershed in the adjoining South Coastal Basin. However, Well GP#2 is likely located where it may impact recharge to Tubbs Meadow Brook. The DEP-Approved Zone II boundary is delineated for the wells as a group (**Figure 3-4**) and does not provide sufficient detail to estimate the zones of contribution within the Jones River Watershed to the wells outside of the watershed. The wells have a DEP-listed capacity of between 350 and 720 gpm and range in depth from 35 to 106 feet.

4.14 Town of Duxbury Water Supply System

The Town of Duxbury operates a total of 10 wells which are registered or permitted to withdraw a total of 1.85 MGD. Duxbury maintains one well within the Jones River Watershed at Lake Shore Drive near Lower Chandler Pond. This well has a DEP-listed maximum capacity of 350 gpm and has a depth of 48 feet. The Lake Shore Drive well was registered with five other wells for a total of 1.23 MGD. In 2000, Duxbury pumped an average of 0.23 MGD from the Lake Shore Drive well, which was operated a total of 136 days of the year.

The Towns of Plympton, Plymouth, and Halifax do not have municipal water supply sources in the Jones River Watershed.

4.20 OTHER WATER USERS

As shown on **Figure 4-3**, cranberry bogs populate a large portion of the study area and play a significant part in the hydrologic setting of the basin. The WMA requires bog owners of greater than 4.66 acres of cultivated land to obtain a permit. Up to 20 bog owners are listed in **Appendix H** (DEP WMA database) which may be included in the Jones River Watershed. According to the land use GIS layer obtained from MassGIS, 4.9 percent or about 930 acres of the watershed is utilized for cranberry cultivation. **Table 2-6a** breaks down the cranberry-growing acreage by subbasin, according to the land use data. Although the land use data is dated 1999, this estimate may be conservative and may not reflect the growing number of abandoned and/or converted cranberry bogs (and thus the decrease in bog acreage). An additional estimate was made by GZA using another MassGIS data layer: Orthophoto Wetlands and Streams. The wetlands layer was developed by the University of Massachusetts at Amherst using stereo, 1:12,000 scale color-infrared photography and field checked by the DEP Wetlands Conservancy Program (WCP). Cranberry bogs are estimated to cover 2.8 percent of the watershed, or about 530 acres, based on the wetlands GIS layer. A final estimate was completed by combining GIS-based analysis of the USGS topographic map and orthophoto quadrangles (Figure 4-1) with the aforementioned layers and the DEP/MassGIS Abandoned Cranberry Bog layer, which resulted in about 737 acres of active bogs.

A number of factors affect the water needs and water use of cranberry bogs. Several USGS, USDA, and NRCS (formerly SCS) studies describe these relationships in detail. In summary, the amount of water needed is a function of the levelness of the bog, the presence of sprinklers, the surficial geology of the bog (water-holding), and tailwater recovery. For WMA purposes, DEP has adopted a standard of about 10 acre-feet of water needed for each acre of bog annually, based on research of bog operations conducted by the SCS in the 1980s[16]. Bog operators typically utilize water for spring frost flood, summer irrigation, fall frost flood, harvest, and winter flood protection in the following manner:

Spring Frost:	1.8 acre-feet per acre
Summer Irrigation:	1.0 acre-feet per acre
Fall Frost:	1.3 acre-feet per acre
Harvest:	1.5 acre-feet per acre
Winter Flood Protection:	4.5 acre-feet per acre
Total:	10.1 acre-feet per acre

Much of the water use occurs during October through December. Based on peak usage, the WMA considers 100,000 gpd of consumptive use for every 4.66 acres of typical bog. Water conservation measures can improve this ratio to 100,000 gpd for every 9.33 acres of bog[17].

Using the DEP method, a total of about 15.8 MGD of water is needed by the cranberry growers of the watershed (based on 737 acres of bog). The WMA considers the cranberry bog water need as the registered and permitted volume of water. This approach is conservative, as it assumes that the entirety of water used is consumed by the bog vegetation. Reported consumptive use values range from zero (Gilmore Associates) to 17 inches per year (USGS). Clearly, the presence of a flooded bog exposes water to additional evapotranspiration it may not be exposed to under natural conditions. This is especially true for bogs that irrigate using groundwater supplies. During non-growing season flooding for frost protection, winter flooding, and harvesting is returned to the basin with limited consumptive loss.[18] By impounding water during this period, the bog potentially alters the streamflow regime (depending on the timing of water releases), decreases streamflow in an amount equal to consumptive use, and increases ground-water storage in the vicinity of the impounded reservoirs and some bogs.[19] Final estimates of cranberry bog acreage and water use are provided in **Table 4-15**. For our water budget model, cranberry bog consumptive water use was represented by applying potential evapotranspiration over the total bog acreage during the period of typical bog flooding (i.e., harvest, frost protection, etc.).

[16] Gilmore Associates, Untitled Report, 1984.
[17] Massachusetts DEP, Correspondence from Mr. Andrew Gottlieb, Manager, Water Management Program to Mr. Jeffrey Carlson, Exec. Director, CCCGA, August 7, 1992.
[18] USGS, "Geohydrology and Simulated Ground-Water Flow, Plymouth-Carver Aquifer, Southeastern Massachusetts," WRI 90-4204, 1992, p.11.
[19] Ibid, p. 11.

4.30 WATER DEMAND AND USE

Water from the Jones River watershed is used both within and outside the watershed for a variety of purposes. Water use is considered a debit from the overall water budget. Some of the withdrawn water is recycled within the watershed in the form of return flows (i.e. recharge from septic systems, lawn watering, etc.) Other water is immediately exported from the watershed for use. A summary of public water suppliers is given in **Table 4-4**.

4.31 Service Area

Four water suppliers withdraw water from the Jones River watershed. Some of the water withdrawn by the Towns listed in Table 4-4 is sold to other public water suppliers. However, this does not impact water budget calculations, which considers water withdrawals and return flows (and not the particulars of what happens after water is withdrawn). For example, the City of Brockton supplies Hanson and Whitman with water, but since each of these communities is out of the watershed area, all water withdrawn by Brockton is considered to be "lost" from the Jones River basin. A similar situation exists in Duxbury, whereby the Town purchases water from and sells to the Town of Marshfield.

4.32 Water Users And Service Population

Water is withdrawn from the Jones River watershed for use by domestic, commercial, industrial, agricultural, and municipal users. Information from the water suppliers regarding current population and percent coverage was used to estimate the service population of the water utility. The "adjusted service population" includes the seasonal population multiplied by an adjustment factor. **Table 4-5** shows current total service populations for the various water suppliers. The current total adjusted service population provided with water from the Jones River watershed is about 123,122.

By using population forecasts, developed by the Metropolitan Area Planning Commission (MAPC), for the towns of the watershed, GZA projected the service population forward into the future as shown in **Table 4-6**. Service percentages for Towns such as Hanson were assumed to be constant (same as in **Table 4-5**). The Town of Plympton is assumed to remain self-supplied. Using the MAPC data, the total service population of the Jones River watershed (the population using water derived from the Jones River watershed) is projected to increase slightly to about 123,530 by the year 2020. Data from the EOEA Build Out studies was also compiled and included in Table 4-5. The projected service population under build out conditions is about 149,370.

4.33 Total Water Demand

The total amount of water withdrawn for use from the Jones River watershed is the sum of the withdrawals by the public water suppliers, self-supplied private water users, and agricultural users such as the cranberry growers. Total water demand from the public water suppliers and domestic self-suppliers is shown in **Table 4-7a and b** (Plympton self-suppliers are not shown on Table 4-7a due to a lack of data regarding annual water consumption). Note that much of the data on self-supplied users (a relatively small proportion of all users in the study) has been assumed using the typical values[20]. Based on data from 1996 through 2000 DEP Public Water Supply Annual Statistical Reports, total water demand was about 5,400 million gallons per year, which is equivalent to an average daily demand (ADD) of 11.94 million gallons per day (MGD) from the Jones River Watershed. The majority of the demand, 10.53 MGD, is from the Brockton Water Commission system (i.e., Brockton, Whitman, and Hanson).

There is significant monthly variability to water use due to temperature, rainfall, air conditioner use, lawn watering, seasonal population change, and other factors. **Table 4-8a and b** show the average monthly usage of the main water suppliers / users in the Jones River watershed, based on DEP statistical reports. The difference in the total use monthly percentage versus the Jones River monthly percentages is mainly due to the operating schedules of various wells. In general, demand is lowest in February and peaks in June and July. Maximum Daily Demands for 1996-2000 are shown in **Table 4-7a and b**, and the average peaking factor is approximately 1.5.

4.34 Distribution of Water Usage and Per Capita Consumption

The largest single user group is residential (domestic) users, but other groups also purchase and utilize water. **Table 4-9** lists the current estimated distribution of water deliveries to various groups by the major water suppliers, based on averaged 1996-2000 data (does not include cranberry growers and other self-supplied agricultural users). Residential users accounted for over 65 percent of total public water supply demand. “Other” demand (metered usage which is not reported in other categories, such as metered fire flows) was the second largest category at about 13 percent, followed by “Unaccounted-for” demand (which is unmetered use or leakage) and commercial demand.

GZA estimated the per capita demand for the Jones River watershed based on the total amount of water delivered, the service population, and water supply distribution percentages. Two measurements of per capita demand are generally of interest: The actual residential per capita demand is a measure of the amount of water used by each individual consumer drawing water from the watershed and is computed by dividing the volume of water delivered to residential customers by the service population. The gross (base) per capita demand is a measure of the total amount of water used by the community to support each of its citizens (including commercial use, etc.). This figure is computed by taking the total amount of water used and dividing by the service population. **Table 4-10** lists the 1996-2000 residential and gross (base) per capita demand for water from the various suppliers in the watershed. These figures represent the per capita demand of the population which actually draws water from the watershed. This group overlaps but is not the same as the population which lives within the watershed boundaries. The actual per capita demand figures should be similar for these two populations. The actual residential per capita

[20] Solley et al, “Estimated uses of water in the US in 1995,” USGS Circular 1200, 1998.

demand ranges from 62.3 gallons per capita per day (gpcd) for the Brockton Water Commission to 87.5 gpcd in Duxbury, and the gross (base) per capita demand ranges from 72.7 gpcd in Pembroke to 108.7 gpcd in Kingston. Self-supplied usage in Plympton was estimated based on data from the USGS publication "Estimated Use of Water in the United States, 1995". A domestic per capita demand of 68 gpcd was selected for self-supplied users in Massachusetts, and a per capita demand of 114 gpcd was selected for the gross demand estimate. The gross estimate is based on total self-supplied per capita usage, minus the industrial and thermo-electric per capita usage, which are assumed to be non-existent in the area of Plympton within the limits of the Jones River Watershed.

4.35 Water Use Trends and Projected Future Needs

Prediction of future water need is an often imprecise exercise. Estimating future need in general depends on the extrapolation of historical trends in population and demand, and is dependent on a number of base assumptions. Such extrapolations usually become less accurate as the prediction period is extended, due to influences that cannot be anticipated. A certain amount of variability in various forecasts is due to use of different projection methodologies. This study will adopt the most current methodologies developed by the Massachusetts Water Resources Commission.

A 1997 Camp Dresser & McKee (CDM) report for the City of Brockton[21] cited demand projections previously made by the Massachusetts Department of Environmental Management – Office of Water Resources (DEM-OWR) for the Brockton Water Company (includes Brockton, Whitman, and Hanson). The total average daily demand projection for 2020 was 14.78 MGD (5,398 MG per year). If current supply patterns remain constant, these projected demands would correspond to 13.71 MGD (5,007 MG per year) from the Jones River watershed in 2020. This DEM-OWR demand projection is 37 percent higher than GZA's demand projection. There are two likely reasons why these two projections differ. Firstly, DEM-OWR relied upon Massachusetts Institute for Social and Economic Research (MISER) projections for 2020 population, whereas GZA relied upon Metropolitan Area Planning Council (MAPC) projections for 2020 population. MISER projected the 2020 total population for Brockton, Whitman, and Hanson to be 139,655, whereas MAPC projected the 2020 total population to be 115,269, a difference of roughly 21 percent. Secondly, according to the CDM report, "Brockton is required by state law to provide Hanson with water, so Brockton must plan to provide the Hanson demand even if the town is able to develop its own supplies." The DEM-OWR projections account for 100 percent of Hanson's water needs, whereas GZA's projections are based upon recent (1996 to 2000) supply patterns which show that the Brockton W.C. provides for only about 7 percent of Hanson's water needs. According to DEM-OWR, their projections were specifically developed to assist Brockton in development of a new source, and required them to look at a "worst-case" scenario. These projections were therefore not officially adopted by the Massachusetts Water Resources Commission.

[21] City of Brockton, "Taunton River Water Supply Supplemental Draft Environmental Impact Report (EOEA No. 8788)." August 1997. Prepared by Camp Dresser & McKee.

The Massachusetts Department of Environmental Management – Office of Water Resources (DEM-OWR) made demand projections for the towns in the South Coastal watershed in 1991 as part of the WRC/DEM River Basin Planning program. Once approved by the WRC, the forecasts can be used by water suppliers in their Water Management Act permit applications. DEM-OWR projected that average daily demand (ADD) in Duxbury, Kingston, and Pembroke by the year 2020 would be 1.64 MGD (599 MG per year), 1.57 MGD (573 MG per year), and 1.28 MGD (468 MG per year), respectively. If current supply patterns remain constant, these projected demands would correspond to 0.14 MGD (52 MG per year), 1.57 MGD (573 MG per year), and 0.27 MGD (100 MG per year), respectively from the Jones River watershed.

The DEM-OWR projections are consistent (within approximately 10 percent) with GZA's projected demands for the Jones River Watershed sources for the year 2020 of 0.16 MGD (58 MG per year), 1.50 MGD (548 MG per year), and 0.28 MGD (102 MG per year), respectively. The DEM-OWR 2000 ADD projections for Duxbury, Kingston, and Pembroke (as adjusted for the Jones River Watershed Sources) were 0.13 MGD (48 MG per year), 1.50 MGD (549 MG per year), and 0.26 MGD (95 MG per year), respectively. Based on information provided on DEP Office of Watershed Management Annual Water Supply Statistical Reports, the base ADD in the year 2000 from Jones River Watershed sources for these three communities was 0.13 MGD (48 MG per year), 1.28 MGD (468 MG per year), and 0.26 MGD (95 MG per year), respectively. The DEM-OWR demand projections for the year 2000 for the towns of Duxbury and Pembroke agree with the actual base ADD, while the projection for the town of Kingston is somewhat high.

The projections made by DEM in the 1991 study were done with a methodology that is no longer utilized by DEM. The Massachusetts Water Resources Commission (MWRC) and DEM-OWR currently utilize two other methods for forecasting future water needs[22]. Method 1 is used for communities where three criteria are met: 1) Sufficient disaggregated water use data; 2) residential gallons per capita daily use (gpcd) of 80 or less; 3) unaccounted-for water factor of 15 percent or less. Method 2 is used when one or more of these criteria is not met. Method 1 was chosen as the preferred forecasting technique for the Brockton and Kingston systems, as they meet all of the aforementioned criteria. Method 2 was chosen as the preferred forecasting technique for Duxbury, Pembroke, and Plympton systems; Duxbury has a residential daily use of greater than 80 gpcd, Pembroke has unaccounted for water greater than 15 percent, and Plympton self-supplied users have insufficient disaggregated water use data. Using the appropriate forecasting method for each community in the watershed, the estimated average daily demand in 2020 for water from the watershed is 12.05 MGD, as shown in **Table 4-11** and **Table 4-12**. The disadvantage of Method 2 is that it does not allow for a projected decrease in unaccounted-for losses.

In using the MWRC / DEM-OWR methods, U.S. Census Bureau data was used for

[22] Massachusetts Water Resources Commission / DEM – OWR. "River Basin Planning Program – Generic Water Needs Forecasting Methodology." DEM – OWR Internal Document.

2000 and population projections from MAPC were used for 2010 and 2020. Seasonal population in Duxbury was assumed steady at 2,000. Percent of population served in each community was held constant. An analysis of water use by user classification for the watershed communities is shown in **Table 4-9**. Based on this data and MWRC / DEM-OWR procedures, projected per capita residential and non-residential demand was held constant. Unaccounted-for losses in the Kingston system were steadily decreased to 10 percent in 2020 for the Method 1 forecast.

The results of the water needs projections are summarized in **Table 4-12** and compared to previous unofficial DEM-OWR estimates in **Table 4-13**. As discussed above, the results of <u>Method 1</u> will be used for the purposes of this report for the Brockton and Kingston systems, while the results of <u>Method 2</u> will be used for the purposes of this report for the Duxbury, Pembroke, and Plympton systems. If in the future, Pembroke is able to reduce its percentage of unaccounted for water and Duxbury is able to curb residential per-capita demand, Method 1 may be a more appropriate forecasting technique for these two systems.

The total watershed average daily demand for 2020 is estimated to be 12.05 MGD. Accounting for the predicted increase in service population, the average per capita demand in 2020 is estimated as 96.2 gallons per capita per day, which would be a 0.04 percent average annual (non-linear) decrease between 2000 and 2020. The changes in demand between 2000 and 2020 are a result of two primary factors: the projected steady population growth in the communities of Duxbury, Kingston, Pembroke, and Plympton, and the projected dip in the population of the city of Brockton.

The total population within the communities of Duxbury, Kingston, Pembroke, and Plympton served by sources within the Jones River Watershed in the year 2000 is 17,377 and the population is projected to increase about 25 percent to 21,626 by the year 2020. The gross (base) per capita consumption for these same four communities in the year 2000 is 98.4 gpcd and is projected to decrease about 5 percent to 93.4 by the year 2020. The decrease in per capita consumption is due to the assumption that the Kingston and Pembroke Water Districts will identify and correct the causes of their current high rate of unaccounted-for water loss. Increases in water costs, conservation measures, and/or limits on supply may impact future demand (and thus per capita consumption) projections, however.

Based on U.S. Census Bureau figures, the 2000 population of the City of Brockton served by sources within the Jones River Watershed is 91,569. Based on Metropolitan Area Planning Council (MAPC) population projections, the projected adjusted service population in 2010 for Brockton is 87,219 and the projected adjusted service population in 2020 is 86,992; the projected decrease in adjusted service population between 2000 and 2020 is about 5 percent. The Towns of Whitman and Hanson, also served by the Brockton Water Commission, are both projected to have a steady increase in adjusted service population between 2000 and 2020. The adjusted service population of Whitman is projected to increase from 13,479 in 2000 to 14,069 in 2020, an increase of roughly

4 percent. The adjusted service population of Hanson is projected to increase from 696 in 2000 to 883 in 2020, an increase of roughly 27 percent. Note that the population served within the City of Brockton comprises a large majority of those served by Brockton W.C. sources within the Jones River Watershed, roughly 85 percent.

Using the MAPC population projections described above, the forecasted gross (base) average daily demand for the Brockton W.C. for 2010 is 9.95 MGD (3632 MG per year), and for 2020 is 10.04 MGD (3665 MG per year). These projections are roughly a 3 and 2 percent decrease, respectively, from the gross (base) average daily demand for the Brockton W.C. in 2000 of 10.23 MGD (3734 MG per year). Refer to **Table 4-11**.

The 2020 demand projections for gross (base) average daily demand from sources within the Jones River Watershed for each of the water suppliers are all within the registered and permitted average daily withdrawal rates. Refer to **Table 4-1** for information concerning the registered and permitted withdrawal rates for each of the water suppliers, and refer to **Table 4-2** for a breakdown of the approved daily pumping volume and safe yield for each of the sources within the Jones River watershed.

4.40 RETURN FLOWS

Return flow refers to water which remains in the watershed water budget after consumptive use. Return flows are available for additional re-uses within the basin and are not subtracted from the overall water budget. Although not considered for GZA's water budget, the quality of return flows may restrict the possible uses of return flows in some cases if water is not adequately treated before discharge.

After water is used by consumers it is discharged to either a municipal sewer system or an on-site septic system. The majority of the wastewater collection in the Jones River watershed is through private septic systems. Currently, the Town of Kingston is connecting up to about 1,300 homes and businesses, or about 30 percent of the Town of Kingston to the newly constructed recharging sewer system[23]. Wastewater which is collected will be recharged following treatment to groundwater near the border of the Smelt Brook/Tidal subbasin.

The remaining portions of the watershed are served by individual, onsite (Title 5) septic systems. Septic systems generally use small underground tanks to collect wastewater and treat it through sedimentation and biological action. After passing through the tank, the wastewater is removed by allowing it to infiltrate into the ground, usually through buried perforated pipes. Some of the water discharged from septic systems may be transpired by overlying plants, but most of it filters through the soil and infiltrates to the water table below. If the septic system is within the watershed, then the water is once again available as outflow (baseflow) to streams or as supply to be withdrawn from wells downgradient of the septic system. The majority of the water is, in essence, recycled. For the purposes of

[23] Personal communication, Town of Kingston Water Dept.

our water budget, we shall employ a consumptive loss factor for municipal and residential use of 13.6 percent.[24] Consumptive loss is the portion of water demand which does not return to a septic or sewer system as waste water. For instance, some water is lost to evaporation from lawns and pools or is consumed in industrial processes.

Water which is withdrawn from the watershed, but utilized and discharged outside of the watershed represents an overall debit to the water budget. This water is not available to recharge the groundwater of the Jones River watershed. For example, water withdrawn by the City of Brockton is discharged to the Taunton River watershed.

The ultimate fate of wastewater is therefore important to the overall basin water budget. **Table 4-14** lists the quantities of wastewater that are assumed to reinfiltrate into watershed groundwater aquifers based on population, per capita consumption, sewer coverage, and a factor for consumptive uses such as lawn watering. Overall, approximately 12 percent of the water withdrawn is discharged via septic systems within the watershed, resulting in an estimated 1.48 MGD return flow to the watershed.

Stormwater and street drainage systems were observed during field reconnaissance throughout the watershed. Stormwater runoff appears to discharge locally to nearby streams (i.e., in-basin discharge). Stormwater is considered to be part of overall surface runoff in the water budget, and the limited presence of drainage structures is not anticipated to affect the water budget.

4.50 REPORTED SAFE YIELD (SILVER LAKE)

Safe Yield is a hydrologic term with several different meanings. One common definition of Safe Yield is, "The maximum quantity of water which can be guaranteed during a critical dry period."[25] Knowledge of the safe yield associated with a water source (reservoir, aquifer, watershed, etc.) is important to prevent demand from exceeding the available and reliable supply. During periods when water is abundant, the available supply may far exceed the estimated safe yield, but during drought conditions supply will be reduced. Safe Yield generally represents the long-term quantity of water which would be available under expected drought conditions, and traditionally does not account for the water needs of aquatic wildlife.

Estimates of the Safe Yield, as defined as "the highest level of demand that can be met continuously, without failure, in a simulation of the 1960s drought period", have been made for the Silver Lake system by Camp Dresser and McKee, Inc. (CDM) for the City of Brockton as part of their search for supplemental water supply[26]. CDM has developed a mass-balance computer program called RESSIM for the simulation of the lake level. This program was reportedly calibrated based on pumping records, lake elevations, stage/storage relationships, system losses, and rainfall data. The uncertainty regarding the diversions

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[24] Solley et al, "Estimated uses of water in the US in 1995" USGS Circular 1200, 1998.
[25] Linsley, R.K. and Franzini, J.B. Water-Resources Engineering. McGraw-Hill. 1964.
[26] CDM, Draft Report to City of Brockton, Commissioner of Public Works, September 2, 1987.

from Monponsett and Furnace Ponds (namely the diversion conditions discussed in Section 4.11, the use of these waters by local cranberry growers, and the downstream releases of the waters of the Ponds) affect the safe yield estimate. As a result, the 1987 CDM report provides a range of safe yields of the Silver Lake system, between 8.3 and 10.0 MGD, which includes the contributing drainage area of Furnace and Monponsett Ponds. The withdrawals made from the Silver Lake system are often greater than the reported 10.0 MGD safe yield (see Section 4.10). This may have implications for the stability of the Brockton water supply system during drought conditions, as withdrawals from Silver Lake may not be available when its water level decreases to unusable elevations.

The report also examined the safe yield of Pine Brook through regression analyses of measured flow data and correlation to continuous flow records at the Neponset River in Norwood, Massachusetts. Based on these calculations, the safe yield from Pine Brook, given the diversion scenario to Silver Lake, is about 0.5 MGD.

As a check of the reported yield estimates, GZA performed a brief analysis of the firm yield of Silver Lake using the DEP's Firm Yield estimating software package.[27] The algorithms employed by the software are those recommended by the Massachusetts Department of Environmental Protection (DEP) in its January 1996 Guidance Document entitled "Estimating the Firm Yield of a Surface Water Reservoir Supply System in Massachusetts" (DEP, 1996). Developed for the Massachusetts Department of Environmental Protection by Cambridge Environmental Inc., the software package uses streamflow data and climatic data, in this case from the Jones River USGS gage and Plymouth-Kingston weather station, respectively, along with estimates of watershed and water body characteristics to estimate firm yield. The GZA analysis indicated a firm yield of 4.7 MGD from the Lake, neglecting diversions from Furnace and Monponsett Ponds. Diversions were neglected since they are not permitted during periods of typical drought conditions, which are anticipated to occur sometime between June and September. In reality, the diversions from Furnace and Monponsett Pond only can assure a Lake elevation at or just above full spillway elevation at the end of May, and cannot realistically guarantee substantially greater capacity for water use during the summer months. This is because the Lake, under natural conditions (i.e., without diversions and water withdrawals), is anticipated to more or less refill during the typical winter and spring, assuming average precipitation in the watershed. (see Section 5.0 for additional information). Summary information and DEP Firm Yield Estimator model input is provided in Appendix B.

[27] MADEP, Firm Yield Estimator Version 1.0, July 2000.

5.00 INFLOW / OUTFLOW ANALYSIS

GZA completed an inflow / outflow analysis using a simple water budget model, based on the principals of the hydrologic cycle in conjunction with statistical analyses of existing data from the USGS stream gage on the Jones River at Elm Street; precipitation data from the DEM and the NCDC; and general watershed characteristics. The inflow / outflow analysis evaluated so-called "average" precipitation conditions, as well as "dry" precipitation conditions, which utilized a 1-in-20 dry year (i.e., 95 percent exceedence interval). Results of the inflow / outflow analyses are discussed in Section 5.30.

5.10 WATER BUDGET DEVELOPMENT

A water budget is an accounting of water flowing into, out of, and/or stored within a watershed or subbasin. The water budget developed by GZA for this study is a one-dimensional model with a monthly time step, applied to each subbasin. Inflow in the form of precipitation and stream flow in a subbasin is balanced against outflow which occurs as evapotranspiration, stream flow out of a subbasin, and/or withdrawal(s). By accounting for all storage and transfer terms, and by varying the inputs and withdrawals, various drought and demand scenarios may be considered using the water budget methodology.

In developing the water budget model and the hydrologic characteristics of the Jones River watershed, GZA used general methodologies described in publications such as the USGS Water Resource Inventory Bulletins.[28] These publications have provided good general information on surface and groundwater resources. GZA utilized similar water budget methodology for the DEM in "Status of and Potential Impacts on the Water Budget for the Weir River Watershed, Final Report," dated June, 2002.

The spreadsheet-based model developed by GZA was calibrated and verified based on the four most recent "water" years of available streamflow data (i.e., water years 1997 to 2000). We then statistically applied this data to each of the eight subbasins that comprise the Jones River Watershed. The results of the water budget model were then used to investigate the relationship between water demand and the aquatic environment, as described in Section 6.00. A separate model was developed to simulate the daily water surface elevations in Silver Lake and estimate flows from the Lake to the Upper Jones River, as described in Section 5.13.

5.11 Limitations

Based on GZA's scope of work and budget, the water budget model developed for application to the Jones River watershed is a simplified, monthly time-step model. As

[28] These reports include: Mazzaferro, D.L., Handman, E.H., Thomas, M.P., "Water Resource Inventory of Connecticut - Part 8 - Quinnipiac River Basin", prepared by USGS in cooperation with CTDEP, Connecticut Water Resource Bulletin No. 27 (1979).

such, it is inappropriate to attempt to derive and evaluate the magnitude and frequency of extreme low flows, such as the 7Q10, through the use of the model nor is it valid to forecast river or flood flows at a river reach-specific level. In addition, the model does not directly consider or differentiate between intricate, highly-transient hydrologic functions occurring within the watershed subbasins such as soil moisture conditions, areas of stream/well recharge vs. water table recharge, and site-specific return flow/recharge area geologic characteristics. The model does not account for transient effects and time lag normally associated with the runoff/recharge/baseflow process.

Additionally, as the model was applied on a sub-basin scale, the results of the model indicate flow at the outlet of each basin and not necessarily at particular stream locations throughout a sub-basin. The magnitude of estimated flows at the outlet of the basin do not necessarily indicate the magnitude of flows throughout the basin, particularly in the upper reaches of a sub-watershed. Local, reach-specific impacts may be occurring in subbasins that are estimated to have relatively abundant streamflow.

Although the model does consider human impacts to the watershed, it assumes that the physical alteration of the watershed and any land use changes occurring within the watershed from natural to developed and future scenarios are not of sufficient magnitude to have significant impacts on streamflow, on a monthly, watershed-wide basis. Of course, if unchecked development promulgates throughout a watershed, impervious areas will likely increase. Such an increase may lead to reduced areas of potential infiltration which may have a negative impact on base flow. However, the Commonwealth of Massachusetts stormwater policy[29] contains specific requirements for the preservation of groundwater recharge for development or redevelopment projects.

5.12 Subbasin Monthly Water Budget

A primary goal of this study and key rationale for developing the water budget was to investigate whether or not water withdrawal affects the quantity and quality of aquatic habitat based on resultant stream flows at various times of the year. Therefore, one of the most important outputs from the water budget model is the quantity of predicted flow within the study subbasins during each month. The groundwater **baseflow** component of total streamflow is likely most critical for sustaining aquatic communities (i.e. macro-invertebrates, fisheries) during the limiting summer months. Baseflow is that portion of the overall stream flow which is provided by groundwater outflow into the stream. The remaining fraction of total streamflow is made up of surface water runoff. For a small watershed such as the Jones River basin, the surface water runoff component is often too transient and flashy in the summer months (especially when estimated on an average monthly basis) to be important for biologic activity. Average summer baseflow is likely to be a more accurate predictor of the mean total summer streamflow (which is the parameter preferred by USFWS in its New England Aquatic Base Flow or ABF Policy).

[29] Massachusetts DEP, “Stormwater Management, Volume I: Stormwater Policy Handbook,” March, 1997.

For this study (and in the previously published Weir River Study), GZA used standard hydrologic balance theory to fashion a method of predicting resultant average monthly streamflow and baseflow from estimates of watershed recharge and incremental changes in (i.e., losses and gains) in aquifer storage. The simulation of streamflow and baseflow for the various subbasins within the Jones River watershed was the prime objective of the study. Only from developing a scientific treatment in estimating baseflow from the predominantly ungaged watershed, can a discussion of potential environmental impacts, in general, and aquatic habitat assessment, in particular, be possible.

The following paragraphs provide a detailed discussion of the numerous sequential steps taken by GZA to develop the water budget model (i.e., inflow / outflow analysis). We were fortunate to have over 35-years of daily stream flow data within the study watershed from the USGS gaging station on the Jones River at Elm Street (No. 01105870). This streamflow data was invaluable in developing the baseflow vs. change in aquifer storage relationship for the watershed as a whole, which was subsequently applied to the various subbasins within the Jones River study area. As discussed, below, having site-specific flow data provides us a means to calibrate and verify our modeling approach and results. This creates a more robust model and adds more validity and reliability to the conclusions derived from such methods as opposed to a methodology solely developed by synthetic means, using hydrologic data from nearby, similar watersheds.

We have, via simplified methods, developed a relationship between storage and groundwater baseflow (outflow). Simply put, a means to predict monthly baseflow based on an estimate of monthly change in aquifer storage was required to achieve the study goal. GZA was able to develop a basic relationship between aquifer storage and baseflow through formulating the model first for the watershed contributory to the USGS gage. Model parameters such as the baseflow vs. storage relationship were adjusted to correspond to observed data in a given water year in the calibration process, and the model was applied to separate water years in the verification process. GZA then evaluated how additional changes in aquifer storage (i.e., additional withdrawals) may affect river baseflow and potentially impact local aquatic biology.

The model development process is presented below, with implementation and results described in Section 5.30. The analysis was subsequently carried out on a subbasin level, and incorporated the following input variables: Precipitation, Evapotranspiration, Withdrawals, Streamflow in the Jones River at Elm Street. The objective of the modeling approach was to solve for monthly fluctuation in aquifer storage and predict monthly subbasin streamflow and baseflow rates. Our modeling process consisted of the following steps:

Step 1: Estimate current average monthly total stream flow rates in the Jones River watershed from actual stream gage data. Derive average monthly baseflow rates in the Jones River watershed through USGS program HYSEP (Hydrograph Separation).[30]

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[30] Sloto and Crouse, "HYSEP: A Computer Program for Streamflow Hydrograph Separation and Analysis", USGS WRI 96-4040, 1996.

HYSEP takes average daily data from a USGS gage and estimates percent of total flow which is baseflow. The baseflow percentages derived using HYSEP were normalized (and expressed in units of cfsm).

Although useful for comparison purposes, the existing database of non-continuous flow data cannot be used to confidently establish monthly average flow patterns due to limited periods of record. Continuously recording or daily stream gage data with long periods of record (i.e., sample size) were used to estimate flow patterns in the watershed. As with any other statistical endeavor, the larger the sample size, the higher the confidence in forecasting trends in the data. Monthly average flow estimates based on observed flow data with small and non-uniform sample sizes are susceptible to error based upon potentially extreme climate conditions (i.e., drought, flood), unforeseen conditions (water supply demand fluctuations), and/or flow measurement variability (human error, mechanical defects, etc.).

Step 2: The information obtained from the USGS gage is applicable to the current developed condition, given its 35-year period of record (1966-current). To help derive the storage-baseflow relationship, GZA utilized the Jenkins Method for calculating streamflow depletion due to pumping wells in the contributory watershed[31], and adjusted HYSEP flow data to reflect more natural conditions (i.e., without water withdrawals).

The Jenkins Method provides a simple approach to estimate the effects of groundwater withdrawal on nearby streams. The Jenkins Method allows for estimates of: 1) the rate of stream depletion at any time during the pumping period or the following non-pumping period, 2) the volume of water induced from the stream during any period, and 3) the effects of intermittent pumping. This method was recently used in a similar study conducted on the Ipswich River Basin by the USGS. Estimates of stream depletion are made through the use of a series of dimensionless curves and tables. Key input parameters include aquifer storativity and the transmissivity, the steady pumping rate, pumping time, and the perpendicular distance from the pumping well to the stream. The Jenkins Method calculations are provided in Appendix B. The depletion of the nearest stream was estimated for each pumping well based on the monthly pumping records from the average of 1996-2000 DEP Public Water Supply Annual Statistics Report.

Step 3: Calculate monthly water budget for average year climate conditions (precipitation) for the Jones River watershed at the USGS gage. Input baseflows found in Step 2. Label the initial storage condition as “zero” (an arbitrary assignment). Storage values which are estimated in the process will be relative to this existing condition. Solve for monthly change in storage (the difference between inflows and outflows).

Step 4: Plot relative storage per square mile of watershed at time (t) vs. baseflow per square mile of watershed at time (t+1). Use these 12 data points to develop what is essentially a “rating curve” of Storage vs. Baseflow for the Jones River watershed

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[31] C.T. Jenkins, “Computation of Rate and Volume of Stream Depletion by Wells,” Techniques of Water-Resources Investigations of the USGS, Book 4, Chapter D1, 1977.

contributory to the USGS gage. An exponential trend line was found to best fit the resulting points (see **Figure 5-1**).

Step 5: To estimate the runoff component of total streamflow, a statistical analysis of rainfall vs. runoff was undertaken for the period of record of the Jones River USGS stream gage and from precipitation records for gages in Plymouth and Pembroke. Runoff quantities at the USGS gage were obtained in Step 1 (HYSEP procedure) in the form of percent of total streamflow comprising baseflow and plotted against monthly precipitation (departure from normal) for each month (i.e., each January from 1966 to 2000, each February from 1966 to 2000, etc.). Again, a best-fit trend line was fitted to the data as seen in **Figure 5-2**. The results allow for an estimation of the percentage of streamflow that is runoff based on total monthly precipitation.

Step 6: After Steps 1 through 5 were completed, the water budget evaluation was calibrated and verified, and then performed for other scenarios (i.e. dry years, etc.), solving for resultant flow in the study stream. Together with the Jenkins Method for calculating streamflow depletion due to pumping wells[32], estimated consumptive usage of cranberry bogs (assumed to be equivalent to estimated evapotranspiration and based upon bog acreage discussed in Section 4.20), and the estimated contribution to the Jones River from Silver Lake we can quantitatively evaluate (at least on a preliminary level) the changes in baseflow and streamflow under natural, current, and future conditions.

Once the model was developed for the USGS gage contributory area, the model was then applied to each subbasin. The established unit baseflow vs. unit storage relationship (**Figure 5-1**) was assumed to be generally representative of each subbasin based on the successful calibration to the USGS gage data. However, the relative flows for each subbasin were weighted based on the 1991 USGS Aquifer Yield report (**Table 5-1**). The 1991 study, described in Section 3.41, estimated aquifer yield (i.e., groundwater outflow) on a subbasin level. Accounting for the variable flows in each subbasin was accomplished by using a weighting factor, calculated by dividing the estimated baseflow for the month of September by the 80-percent yield estimate provided by the USGS. This method was selected because our USGS gage contributory watershed water budget model resulted in estimated September baseflows equivalent to the 80-percent exceedence value of the flow duration curve at the USGS gage. The estimated baseflows and streamflows for each subbasin were subsequently multiplied by the weighting factor to estimate their relative contribution to the overall flow in the Jones River. The sum of the weighted USGS-gage-contributory subbasin model monthly baseflow estimates compare favorably with the overall USGS-gage-watershed model monthly estimates. Refer to Section 5.22.

A detailed description of the model spreadsheet entries is provided in **Appendix B**. In addition, the equations relating the pertinent parameters of the water budget (i.e., precipitation, evapotranspiration, runoff, baseflow, withdrawals, etc.) and spreadsheets are in **Appendix B**.

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[32] C.T. Jenkins, "Computation of Rate and Volume of Stream Depletion by Wells," Techniques of Water-Resources Investigations of the USGS, Book 4, Chapter D1, 1977.

5.13 Silver Lake Daily Water Budget

Since the water level of Silver Lake varies considerably from day to day, a separate lake model was developed to estimate the Lake's daily input to the Upper Jones River. Unlike the subbasin water budget model, a monthly time step is insufficient to accurately estimate the outflows from Forge Pond Dam, in GZA's opinion. The Lake model utilizes the general methodology of the hydrologic cycle. Inflows to the Lake include direct precipitation onto the water surface, streamflow (as estimated from the USGS gage on the Jones River at Elm Street and adjusted for drainage area), induced aquifer leakage to the Lake as a result of relatively rapid water surface fluctuations, and diversions from Monponsett and Furnace Ponds. Outflows from the Lake include flow over the Forge Pond Dam spillway, withdrawals by the City of Brockton, and evapotranspiration.

Daily water withdrawals and diversion data were provided by the City of Brockton for the period beginning in October, 1996. Direct precipitation was estimated based on daily rainfall data at the Plymouth and Pembroke precipitation gages. Evapotranspiration was estimated from pan evaporation data published by the NCDC at the nearest climatologically similar area, Kingston, Rhode Island. Streamflow into the lake was estimated using a drainage area ratio of daily average flow data at the USGS Elm Street gage. To account for the differences in groundwater inflow at the lake, which can fluctuate from its full elevation (47.0 ft) to about 41.0 ft during the past 5 years, a simple Darcy's Law assumption was made. This method assumed a hydraulic conductivity of characteristic of the surrounding subsurface materials (i.e., 0.0005 m/s), a variable hydraulic gradient dependent on the predicted lake level, an assumed surrounding groundwater elevation in nearby subbasins, and a constant length of travel. Given an elevation-storage rating curve, lake levels can then be predicted based on daily changes in storage.

5.20 WATER BUDGET CALIBRATION

Both the lake model and the subbasin water budget models were calibrated to observed flow data at the USGS gage on the Jones River at Elm Street. The water budget model was calibrated based on water year 2000 data and verified using data from water years 1997-1999. The lake model was calibrated to closely match the observed data for the period of record of Brockton data (i.e., October 1996 to the end of water year 2000).

5.21 Water Budget Model Calibration

The observed data for the USGS stream gage at Elm Street served as the basis for model calibration and verification. **Figures 5-3 to 5-6** show the results of the calibration procedure and in general, show sufficient correlation of predicted vs. observed data. As discussed in Section 5.12, the model was initially developed based on the contributory watershed to the USGS gage, since there is not sufficient data on a subbasin level to calibrate nor verify each subbasin water budget model. Only long-term, continuous data can be used to generate the monthly averages which are predicted by the water budget spreadsheet.

Long term and yearly statistics for the entire period of record (1966-water year 2000) at the USGS gage were downloaded from the USGS web site and/or developed using the USGS SWSTAT software package. The average daily streamflow data for the period of record was also obtained and HYSEP baseflow separation was conducted to provide baseline information. The estimated contribution of Silver Lake spillage to Jones River flow was subtracted from the gage data, since GZA's USGS gage drainage area model does not include the portion upstream of Silver Lake. The resulting observed average values were compared to predicted average values for water year 2000 (**Figure 5-3**). The calibration procedure involved slight adjustments to the coefficient (0.7931 initially) and exponent (0.0075 initially) of the exponential best-fit line fit to the baseflow-storage graph (**Figure 5-1**). The following final equation was found to best match the observed data overall:

Baseflow (cfsm) = 0.9 * exp (Storage [Mgal/sq.mi.] * 0.0062)

No changes were made to the runoff-rainfall relationship in this process. These best-fit equations were then applied to water years 1997-1999 to verify their applicability to the basin. In general, the predicted values show good agreement with observed data. As must be expected in a monthly model, issues of "time lag" often arise during months where a majority of precipitation falls during the beginning or end of the month. In these cases the model may over-predict streamflow during the month of observed precipitation and under-predict streamflow during the next month, or vice-versa. High rainfall amounts (i.e, greater than the monthly average) may also cause a problem for the model, which is developed based on long-term averages. The correlation shown in the calibration and verification process, however, is adequate for a simple monthly water budget, in GZA's opinion.

There is also a tendency for the model to overestimate summer baseflows for some of the water years investigated, particularly for those months which experience or occur after months which experience considerably higher than normal precipitation. A potential solution for this is to modify the trendline (for example, 0.7 * exp (Storage * 0.009) to underestimate average baseflows, but better represent summer baseflows. However, this may have adverse effects when attempting to simulate typical year-round flows. It should be noted that in simulating an average year with average precipitation, the undesirable impacts of widely varied monthly precipitation which is observed during particular water years are not likely to occur or skew model results, in GZA's opinion.

5.22 Subbasin Model Weighting

As mentioned briefly in Section 5.12, the calibrated model was divided into subbasin models through the use of weighting factors. The weighting factors are necessary to reflect the varying contribution of each subbasin to the total flow in the Jones River. As evident from existing literature, not all subbasins are created equal in the Jones River watershed—a simple drainage area ratio is not sufficient to distribute flow. The 1991 USGS Aquifer Yield Study was used to distribute the contributing flows for each subbasin. This USGS study estimated aquifer yields for a number of coincidental subbasins in the Jones River Watershed. Aquifer yield, as defined in the Study, was considered to be equivalent to groundwater outflow (i.e., baseflow) for the purposes of weighing flow estimates. The water budget model predicts a baseflow of 13.3 cfs for the month of September at the USGS gage at Elm Street. This value corresponds to an approximately 80-percent exceedence value on the flow-duration curve at the gage. Assuming that each subbasin is coincidentally contributing flow at its 80-percent exceedence value during September, a process of weighting can begin using the USGS 80-percent aquifer yield estimates. For example, the water budget model predicts the Upper Jones River subbasin to contribute a baseflow of about 0.9 cfsm to the overall flow at the USGS gage in the month of September (80-percent exceedence). However, the USGS specifies an 80-percent exceedence aquifer yield of 0.7 cfsm. A weighting factor can be estimated simply by dividing the expected contribution (0.7 cfsm) by the initial predicted contribution (0.9 cfsm). A similar methodology was applied to each subbasin and the results are presented in **Table 5-1**. To check the rationality of this method, each of the four contributing subbasins (Upper Jones River, Pine Brook, Jones River Brook, and Furnace Brook) were weighted, added, and compared to the predictions of the USGS-gage-contributory watershed water budget model. The majority of monthly baseflow estimates of the sum of the individual subbasins were within 1.5 cfs (or roughly 15 percent) of the entire contributory watershed estimates.

5.23 Silver Lake Model Calibration

The daily lake model was calibrated to the period of record (1996-2000) of Brockton's data relating to Silver Lake, since it is more of a continuous model than the monthly subbasin water budget model. **Figure 5-7** shows the results of the calibration process.

The main parameters which were adjusted during the process related to seepage inflow and lake outflow (i.e., weir coefficient of the Forge Pond Dam spillway). A final weir coefficient of 3.3 at the dam's spillway was used in the model. For estimating groundwater inflow, a hydraulic gradient was taken to be the difference between the lake elevation and an assumed groundwater elevation of 50-ft at the upstream boundary (from surrounding subbasins such as Pine Brook), divided by a constant flow length of 4,100 ft. Hydraulic conductivity was estimated as 0.0005 m/s (about 140 ft/day).

In general, the correlation between observed and predicted lake levels is good, with differences of no more than about 1-foot occurring during periods of very low lake level. The model appears to predict elevations greater than 47.0 ft (over the dam's spillway), and therefore outflows to the Upper Jones River, to an acceptable degree for purposes of this study, in GZA's opinion.

5.30 WATER BUDGET RESULTS

As per the scope of the study developed by DEM, the water budget model was used to examine several different scenarios. Three different development scenarios were evaluated and each of them was modeled under two different hydrologic conditions, as described below:

- **Natural Scenario**: Assumed natural conditions which existed before human development of the area and water withdrawals from the watershed.
- **Developed Scenario**: Water demand / withdrawals set at present (average 1996-2000) levels, with diversions to and from the basin.
- **Future Scenario:** Water demand forecast for the year 2020.

It should be noted that the change in percent impervious cover in the watershed was not factored directly into the "developed" and "future" conditions. Although the promulgation of impervious areas can enhance surface runoff and reduce local groundwater recharge, it is assumed to have a minor impact over the long term and over the entire extent of the watershed given the residential and moderately developed nature of the Jones River Basin (see also Section 2.60).

Hydrologic Conditions:

- **Average Year Conditions:** Assumes that rainfall and all other climate inputs are equal to the long-term mean value.
- **Dry Year Conditions:** Assumes rainfall amounts that would likely occur in a 1 in 20 year drought, i.e. 95 percent exceedence. All other climate factors (potential ET, etc.) are assumed average and demand is the same as in the average year condition.

5.31 Subbasin In-Stream Flows Derived from the Water Budget

The water budget methodology discussed above was applied on a subbasin level for natural, developed, and future conditions. Water budget spreadsheets and storage-baseflow trend lines are provided in **Appendix B**. Note that baseflow and total streamflow values provided in the tables **do not** reflect incoming flow from other subbasins.

5.31.1 Silver Lake Subbasin

The 4.1 square-mile Silver Lake Subbasin contains numerous water supply withdrawals and cranberry bog operations. There are an estimated 0.16 square-miles of active cranberry bogs in the basin. The subbasin serves as the headwaters of the Jones River. Lake model results are summarized in **Figures 5-8A through F;** calculations are provided in **Appendix B**. Estimated and observed flow values from Silver Lake are provided in **Table 5-2**.

To estimate “average” elevations and flows in the Lake, average monthly precipitation from Pembroke and Plymouth precipitation gages was distributed evenly over the average number of days with recorded rainfall per month, as reported by the National Weather Service for Boston. The model was run for a series of years to allow for a “warm up” process before monthly Lake elevations achieved consistency from year to year.

The lake model developed by GZA indicates that under current conditions and assuming average withdrawals, diversions, and precipitation, the lake is expected to spill into the Upper Jones River during Spring months. According to observed data (1996 – 2000) supplied by the City of Brockton, the Lake has spilled most often from March until May, but has been known to spill in each month except August and September, depending on climate conditions, withdrawals, and diversions. For the “natural” condition, withdrawals and diversions were removed from the model and the dam essentially replaced with the berm that currently separates Forge Pond from Silver Lake. Under such conditions, the lake level is estimated to vary from just above the berm (assumed elevation 45.0 ft) to about 1-ft above the berm. Estimated natural outflows from Silver Lake range from a low of about 5 cfs (1.2 cfsm) in October to a high of about 38 cfs (9.5 cfsm) in March.

As described in Section 4.35, the predicted future total volume of the City of Brockton’s water withdrawals is forecast to decrease by about 0.2 MGD. This forecast assumes that Brockton continues to supply other Towns with amounts of water consistent with current conditions. For the Silver Lake water budget, future conditions do not significantly differ from existing conditions since the projected water demand is about 98 percent of the current demand. Under dry conditions, outflow values fall to zero under developed and future conditions. The natural condition is also affected by the low precipitation conditions, as minimum outflows fall to as low as 3.8 cfs in October (although even during a dry year, outflows to the Jones River are estimated to occur continuously).

Upon direction from the DEM-OWR, GZA did not consider the establishment of the Bluestone Desalinization Project[33] on the Taunton River in Dighton in the “future” water budget analysis, due to the uncertainty involved in its development. It should be noted, however, that Brockton is considering Bluestone in its future water supply plans and expects the project will provide up to 3.5 MGD[34]. The water obtained from Bluestone may, in turn, lead to a reduced dependence on Silver Lake for water supply purposes. This may provide positive benefits to flows in the Jones River as reflected by higher normal lake levels and more frequent and larger discharges to the upper Jones River. However, in reality, the magnitude of Brockton’s water demand, even if it is supplemented by the Bluestone Project, is not likely by itself, to provide appreciable positive changes to Silver Lake outflow magnitude or frequency.

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[33] Epsilon Associates, “DEIR: Regional Water Supply Project (EOEA #10185),” July 1997.
[34] Personal communication, Brian Creedon, City of Brockton Water Commission Systems Manager.

5.31.2 Upper Jones River Subbasin

The 4.2 square-mile Upper Jones River Subbasin does not contain a public water supply source. There are an estimated 0.21 square-miles of active cranberry bogs in the basin. Water budget results for average and dry-year precipitation conditions are summarized in **Figures 5-9A and 5-9B**, respectively, and calculations are provided in **Appendix B**. Once again, note that baseflow and total streamflow values that follow and are provided in the figures **do not** reflect incoming flow from other subbasins. Under natural conditions, the water budget predicts a minimum baseflow of about 3.1 cfs (0.7 cfsm) and a total streamflow of 4.1 cfs (1.0 cfsm) in September and a maximum baseflow of about 8.8 cfs (2.1 cfsm) and a total streamflow of 11.6 cfs (2.8 cfsm) in April. The developed condition accounts for the estimated consumption of cranberry bog growers, but does not model the effects, if any, of small dams (i.e., Wapping Road, Elm Street, etc.) on basin outflow. The bog operations are predicted to lessen flows by a maximum of 0.6 cfs, which occurs in the month of July. Otherwise, the model predictions are similar to natural conditions. Minimum flows under current conditions occur in September at a baseflow of 2.9 cfs (0.7 cfsm) and streamflow of 3.8 cfs (0.9 cfsm) and maximum flows in April at a baseflow of 8.6 cfs (2.1 cfsm) and streamflow of 11.4 cfs (2.7 cfsm). The scenario remains constant from developed to future conditions since increased demand is considered to be satisfied from supply sources outside the Upper Jones subbasin.

Under dry-year conditions, baseflow and streamflow values fall to approximately 2.0 cfs (0.5 cfsm) and 2.4 cfs (0.6 cfsm), respectively, under natural conditions in September. For developed and future conditions, very little changes: minimum baseflow occurs in August at 1.7 cfs (0.4 cfsm) and streamflow at 2.0 cfs (0.5 cfsm).

5.31.3 Pine Brook Subbasin

The 4.76 square-mile Pine Brook Subbasin contains a public water supply source for the Town of Duxbury (the Lakeshore Drive well). There are also an estimated 0.23 square-miles of active cranberry bogs in the basin. Water budget results are summarized in **Figures 5-10A and 5-10B** and calculations are provided in **Appendix B**. The Pine Brook subbasin is predicted to contribute the least amount of water to the Jones River as compared to the rest of the watershed on a cfsm basis, ranging from 0.3 cfsm in September (baseflow of 1.3 cfs, streamflow of 2.4 cfs) to about 0.8 cfsm in April (baseflow of 3.6 cfs, streamflow of 6.8 cfs) for natural conditions. The water supply and agricultural withdrawals in the developed condition reduce predicted flows slightly (up to 0.3 cfs in the months of June and July) and minimum flows remain in September (baseflow of 1.2 cfs, streamflow of 2.3 cfs). Future predictions are nearly identical to developed flow estimates, since only a slight increase in demand (0.03 MGD) for the Town of Duxbury is anticipated based on DEM forecasting methodology.

Under dry-year conditions, baseflow and streamflow values fall to 0.9 cfs (0.2 cfsm) and 1.2 cfs (0.3 cfsm) in September. Decreases are predicted for each month for all conditions, particularly in the Spring months where baseflows are predicted at only 0.3 cfsm. The low flow conditions are again slightly reduced by developed conditions, as described for average conditions above.

5.31.4 Jones River Brook Subbasin

The 4.8 square-mile Jones River Brook Subbasin does not contain public water supplies, but there are an estimated 0.28 square-miles of active cranberry bogs in the basin. Water budget results are summarized in **Figures 5-11A and 5-11B** and calculations are provided in **Appendix B**. As expected, natural flows reach a minimum in September and a maximum in April. Baseflow ranges from 4.8 cfs to 13.5 cfs (1.0 cfsm to 2.8 cfsm) and streamflows from 6.0 cfs to 16.7 cfs (1.3 cfsm to 3.5 cfsm). The effects of current development impact flows particularly in summer months, reducing predicted baseflows by as much as 1.0 cfs. Future predictions are identical to developed flow estimates, since no new public water supplies are anticipated.

Under natural, dry-year conditions, baseflow and streamflow values fall to as low as 3.2 cfs (0.7 cfsm) and 3.6 cfs (0.8 cfsm), respectively. Decreases are predicted for each month, particularly in the Spring months where baseflows are predicted at about 1.1 cfsm. The low flow conditions are again slightly reduced by developed conditions, as described for average conditions above.

5.31.5 Furnace Brook Subbasin

Furnace Brook Subbasin drains 2.25 square-miles and contains several water supply wells operated by the Town of Kingston. There are also an estimated 0.09 square-miles of active cranberry bogs in the basin. Water budget results are summarized in **Figures 5-12A and 5-12B** and calculations are provided in **Appendix B**. This subbasin is predicted to have the highest baseflow cfsm values of the Jones River watershed subbasins, peaking at 5.9 cfsm (13.2 cfs) in April and reaching a low of 2.0 cfsm (4.6 cfs) in September. Total streamflow follows a similar pattern: 6.6 cfsm (14.8 cfs) in April and reaching a low of 2.3 cfsm (5.1 cfs) in September. The effects of withdrawals / development are most pronounced in summer and fall, reducing baseflows and streamflows by up to 1.8 cfs. However, even with streamflow depletion accounted for, flow for the developed condition remains fairly high: baseflow of 1.9 cfsm (4.3 cfs) and total streamflow of 2.1 cfsm (4.8 cfs) in September. Future predictions are identical to developed flow estimates.

Under natural, dry-year conditions, baseflow and streamflow values fall to as low as 3.0 cfs (1.3 cfsm) and 3.2 cfs (1.4 cfsm), respectively. Decreases are predicted for each month, particularly in the Spring months where baseflows are predicted at 1.1 cfsm. The low flow conditions estimated for natural conditions are again slightly reduced by developed conditions, as described for average conditions above.

5.31.6 Halls Brook Subbasin

Halls Brook has a 4.11 square-mile drainage area and an estimated 0.15 square-miles of active cranberry bogs in the basin. This subbasin is contributory to the tidal portion of the Jones River. Water budget results are summarized in **Figure 5-13A and 5-13B** and calculations are provided in **Appendix B**. Halls Brook is estimated to have baseflow (cfsm) values typical of the average Jones River watershed to the USGS stream gage, peaking at 3.0 cfsm (12.4 cfs) in April and reaching a low of 1.0 cfsm (4.3 cfs) in September. Total streamflow peaks at 3.7 cfsm (15.2 cfs) in April and reaches a low of 1.3 cfsm (5.3 cfs) in September. There are no public water supplies in the watershed, but effects of other withdrawals are seen most clearly in summer and fall, reducing flows by up to about 0.6 cfs. Future predictions are identical to developed flow estimates, since there are no future anticipated additional water supply withdrawals.

Dry-year conditions result in lower baseflow predictions between 0.7 cfsm (2.8 cfs) in September to 1.2 cfsm (4.9 cfs) in April. Streamflow estimates for dry conditions are also a bit lower: 0.8 cfsm (3.2 cfs) in September to 1.4 cfsm (5.8 cfs) in April. The low flow conditions estimated for natural conditions are again slightly reduced by developed conditions, approaching up to 0.7 cfs in the month of July.

5.31.7 Smelt Brook Subbasin

Smelt Brook drains 2.69 square-miles and contains one water supply well operated by the Town of Kingston. There are also an estimated 0.04 square-miles of active cranberry bogs in the basin. Water budget results are summarized in **Figure 5-14A and 5-14B** and calculations are provided in **Appendix B**. This subbasin is predicted to have high baseflow (cfsm) values, similar to the Furnace Brook subbasin: a minimum average baseflow of 1.9 cfsm (5.2 cfs) in September and a maximum of 5.6 cfsm (15.1 cfs) in April. Total streamflow peaks at 6.3 cfsm (16.9 cfs) in April and reaches a low of 2.2 cfsm (5.9 cfs) in September. Under developed conditions, baseflows in April and September are slightly lower: 5.5 cfsm (14.8 cfs) and 1.9 cfsm (5.0 cfs), respectively. Likewise, streamflows are also slightly lower: 2.1 cfsm (5.6 cfs) in September and 6.2 cfsm (16.7 cfs) in April. Future predictions are nearly identical to developed flow estimates, since only a slight increase in demand for the Town of Kingston is anticipated based on DEM forecasting methodology.

Under natural, dry conditions, baseflow and streamflow are predicted to decrease by as much as 70 percent for each month, particularly in the Spring months where baseflows are predicted at 2.2 cfsm in April, compared to 5.6 cfsm in average conditions. The reduction in flow during critical summer months, although not as extreme as Spring months, is also notable: natural baseflow of 1.3 cfsm (3.5 cfs) and streamflow of 1.4 cfsm (3.7 cfs) in September. The low flow conditions estimated for natural conditions are again slightly reduced by developed conditions, as described for average conditions above.

5.31.8 Tidal Subbasin

The tidal portion of the Jones River watershed drains 2.92 square-miles and contains a negligible amount of active cranberry bogs. Although a water budget model was created for this basin, its results are not as informative as for other subbasins, since the variable effects of the tide influence water surface elevations and flows. Water budget results are summarized in **Figure 5-15A and 5-15B** and calculations are provided in **Appendix B**. The natural fresh-water flows in the subbasin are predicted to be quite similar, on a cfsm basis, as the Smelt Brook subbasin: a minimum average baseflow of 1.9 cfsm (5.7 cfs) in September and a maximum of 5.6 cfsm (16.4 cfs) in April. Total streamflow peaks at 6.3 cfsm (18.4 cfs) in April and reaches a low of 2.2 cfsm (6.4 cfs) in September. Since the basin is tidal and susceptible to saltwater intrusion, no water withdrawal development was accounted for in this basin, so the current and future conditions approximate the natural condition.

This subbasin is also home to the Kingston waste water treatment facility, which serves a portion of the Tidal watershed. Since the treatment facility aims to recharge wastewater in-basin, it has been modeled in a similar fashion to existing septic systems.

5.40 IMPLICATIONS

The water budget model for current conditions shows the rivers of the watershed can expect to experience approximately 0.8 cfsm of baseflow, assuming average precipitation and temperatures, during the critical late summer/early fall months and up to 2.5 cfsm during spring. Total streamflows under developed conditions are estimated to range from 1.0 cfsm in late summer/early fall to 3.8 cfsm in spring. Dry-year precipitation conditions reduce the level of expected baseflows to about 0.4 cfsm in late summer/early fall months and 1.0 cfsm in spring under average current withdrawal scenarios.

The water budget models indicate that, as expected, water withdrawals (due to water supply and evapotranspiration losses from cranberry bogs) result in a reduction of baseflow in the streams and rivers of the Jones River watershed, and there is a correlation between the amount of demand and the reduction of flows on the order of 20 to 30 percent of natural estimated values, at maximum. Each subbasin contributes a varying amount of flow to the Jones River: Pine Brook contributes the least on a unitized (cfsm) basis and Furnace Brook and Smelt Brook the most. However, as the geology of the watershed indicates, even Pine Brook can expect to see about 0.3 cfsm in traditionally water-stressed summer months, assuming average precipitation.

Cranberry bog water usage was estimated based upon bog acreage (see Figure 4-3) and evapotranspiration estimates. The monthly model, however, cannot account for the transient effects of day-to-day bog operations on streamflow which may occur as bogs are flooded and drained. Therefore, there may be site-specific impacts to streamflow from day to day based upon the operating procedures at adjacent cranberry bogs.

Silver Lake is predicted to contribute to the Jones River during portions of the spring under current, developed conditions, assuming average precipitation and withdrawals. For the remainder of the year, the elevation of the Lake is predicted to be below the level of the spillway at Forge Pond Dam. When modeling the lake without the dam and without diversions to and from the Lake, an estimated 5 cfs in October to 38 cfs in spring is predicted to flow to the Upper Jones River. For hypothetical, natural “dry” conditions, Silver Lake would have continuously flowed to the Jones River at between about 4 and 37 cfs. Currently, during periods when flow to the Upper Jones River is negligible and during dry weather, the river may not experience significant flow until the contributing drainage area allows for measurable groundwater outflows (baseflow). The effects of Silver Lake flow to the Jones River are potentially considerable. Hypothetically, adding the natural flows from Silver Lake to current streamflows in the Jones River at the USGS stream gage at Elm Street would result in an approximate 30 percent increase in flows in September from a current average streamflow of about 17 cfs to a hypothetical flow of about 22 cfs. Similarly for March, monthly flows would hypothetically increase by about 60 percent from a current average of about 59 cfs to a hypothetical stream flow of 97 cfs.

The water budget model is a tool which allows analyses of all of the sub-basins of the watershed under various scenarios and conditions. The model quantifies the relationship between demand and baseflow. The next step to assessing the impacts of demand on the aquatic environment is to estimate the relationship between baseflow and aquatic habitat. Section 6.0 examines the streams of the watershed from a fisheries perspective. By combining the hydrologic and biologic information developed within body of this report, Aquatic Habitat Firm Yield values are estimated and presented in Section 6.40. General conclusions are presented in Section 7.00.

6.00 AQUATIC HABITAT AND WATER RESOURCES

The inflow / outflow analysis described in Section 5.00 provides preliminary, general guidance as to the hydrologic character in the watershed. The Jones River is estimated to flow between 0.8 cfsm to 2.5 cfsm at the Elm Street Dam, assuming average climatic conditions, under current conditions of development and water withdrawals. The results of GZA's water budget model were used to assess the aquatic habitat of the watershed on a qualitative basis.

6.10 CURRENT AQUATIC HABITAT DESCRIPTION

The Aquatic Resources (fisheries) portion of this report was prepared jointly by GZA and its sub-consultant Kleinschmidt Associates (KA) of Pittsfield, Maine. Mr. Brandon Kulik of KA was the senior fisheries biologist for the project. The methods used in this report are broadly similar to those used in Instream Flow Incremental Methodology (IFIM) studies. The scope of this project did not include a full-scale IFIM study. However, the information developed in this report could be expanded upon during a future IFIM study. Also the goals of the Living Aquatic Resources portion of this report are the same as that of a IFIM study. Specifically, the information presented here is intended to be used as, "[A] support system designed to help natural resources managers and their constituencies determine the benefits or consequences of different water management alternatives."[35] The flora and fauna inventory of the Jones River watershed was presented in Section 2.70.

6.11 Invertebrate Sampling

GZA conducted a brief investigation of the existing macroinvertebrate community in the Jones River. An extensive benthic macroinvertebrate sampling effort was recently completed by the JRWA and is summarized in their report (see Section 2.0 herein). Data generated from the GZA evaluation of the macroinvertebrate community structure, in tandem with the previous surveys conducted in the watershed, will serve as a baseline in future years, and may be used as a an indicator of the effects on biota as a result of stream flow changes. In the sections below, field methods, laboratory procedures, and results are further described in detail.

Sampling Station Selection

Two sampling stations were chosen along the Jones River in Kingston, MA (Figure 3-6). The first station was at Elm Street near the USGS stream gage. The samples were collected directly to the left of the overlook area in Sampson Park on Elm Street. The second station was where Grove Street crosses the Jones River. This station is just upstream of the Elm Street station and is located southeast of Silver Lake. Furthermore, fish sampling has occurred previously at both Elm Street and Grove Street by the MA Division of Marine Fisheries (Section 2.70).

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[35] Bovee, Ken D. et. al. "Stream Habitat Analysis Using the Instream Flow Incremental Methodology". U.S. Geological Survey, BRD-1998-0004, 1998.

Sampling Methods

GZA used a D-frame kick-net to collect benthic macroinvertebrates on October 24, 2001. The net was used to collect organisms located on the surface of the sediments as well as within the submerged aquatic vegetation. The net was swept from downstream to upstream to collect organisms along the sediment surface and as they floated downstream. The samples collected in the net were shaken into a 500 μm screen pan. The screen allowed for sediments to settle out from the sample and for easier removal of leaves and twigs. The remaining sample was then transferred to a shallow pan. Water was added to the shallow pan to facilitate picking out the macroinvertebrates. Fine forceps were used to pick the organisms from the shallow pan and place them into glass jars filled with buffered 70 percent ethanol for transportation back to the laboratory for identification and enumeration.

The objective of the sampling effort was to collect a target number of organisms (*i.e.* approximately 100 organisms) from each site. The time required to retrieve this number of insects was recorded. This recorded amount of time was the "measure of unit effort," which was used to roughly compare abundances of benthic macroinvertebrates among samples.

Laboratory Analysis

At the laboratory, samples were sorted by a GZA biologist using a 10x to 70x stereo dissecting microscope. Organisms were sorted by taxonomic order. After the preliminary sorting, benthic invertebrates were identified to the lowest practical taxonomic level using Merritt and Cummins (1996).

Results

Results of the macroinvertebrate sampling are presented in Table 6-1. For comparison, time for the collection of 100 individuals at Elm Street was approximately one (1) hour. However, time for the collection of 100 individuals at Grove Street was approximately three (3) hours. Therefore, the measure of unit effort at Grove Street was three times that of Elm Street.

At Elm Street, the majority of the collected macroinvertebrates were isopods (62.4 percent) and amphipods (22.1 percent). Organisms of these two orders made up approximately 85 percent of the total. At Grove Street, isopods comprised a majority of the collected macroinvertebrates (49.6 percent). Dipterans, which were all chironomids in the Grove Street sample, comprised 20.4 percent of the total, tricopterans (*i.e.* caddisflies) comprised approximately 12 percent, and hemipterans comprised 11.5 percent of the total. Isopods and chironomids comprised 70 percent of the total macroinvertebrates collected at the sampling location.

Furthermore, the Elm Street macroinvertebrate sample contained organisms representative of seven taxonomic orders. The Grove Street macroinvertebrate sample also contained organisms representative of seven taxonomic orders. However, there were some differences as to which taxonomic orders were present in the samples. For the Elm Street sample, no organisms from Pelecypoda (*e.g.* clams, mussels) or Coleoptera (*e.g.* beetles) were present in the sample. For the Grove Street sample, no individuals from Odonata (*e.g.* dragonflies and damselflies) or Gastropoda (*e.g.* snails, limpets) were present in the sample.

For tricopterans (*i.e.* caddisflies), one family, Limnephilidae, was represented in the Elm Street macroinvertebrate sample. Two families, Limnephilidae and Phryganeidae, were represented in the Grove Street macroinvertebrate sample.

Conclusions

The field investigation of the Jones River documented some differences in the benthic macroinvertebrate community. There seemed to be a greater abundance of organisms at the Elm Street sampling station than at the Grove Street sampling station based on the measure of unit effort. However, the taxonomic diversity between the two sampling locations was similar with seven taxonomic orders represented. The conclusions are similar to the findings in the JRWA report, which indicated the Jones River below Forge Pond Dam contained a less diverse population of benthic aquatic species than much of the remainder of the watershed.

Limitations

As with any study, it is important to note the uncertainties and limitations associated with the sampling effort. As with any method, there are advantages and disadvantages. The kick-net sampling method is easy to employ, and it is an easily replicated method. However, this sampling method may skew the collection towards larger, surface-dwelling organisms. Although the collection of benthic macroinvertebrates may be skewed in comparison to *in–situ* conditions based on the sampling methods, the collections would not be skewed between one another since the same sampling method was employed at both sampling stations. Furthermore, the collection would be skewed in comparison to *in-situ* conditions no matter which sampling method was employed.

6.20 AQUATIC HABITAT SUITABILITY CRITERIA

The suitability of aquatic habitat for the evaluation species and other wildlife which inhabit the streams and rivers of the watershed is closely tied to the stream flow (although other parameters such as substrate and cover are also pertinent). The in-stream flow rate determines the depth, water velocity, and wetted perimeter at each specific stream section, based on the hydraulic characteristics of that particular section. These parameters, in turn, affect the capacity of a section of stream to provide appropriate habitat for fish and other organisms. Low flow rates are of particular concern in regards to habitat suitability. When flow rates are low, corresponding depths, velocities, and wetted perimeter values may be reduced enough to cause stress to aquatic wildlife, and clearly, fish cannot live in stream sections where there is no flow at all.

6.21 Introduction

The focus of this assessment is to characterize how suitability of aquatic habitat in the Jones River below the Silver Lake dam is influenced by flow. The Upper Jones River subbasin is expected to be most impacted by the effects of regulation and affected by low flows, based upon the water budget analysis discussed previously and field observations. The characterization of the Upper Jones River is based on field measurements of representative habitat, a review of basin hydrology, and a qualitative analysis of habitat requirements of a cross-section of representative members of the Jones River aquatic community. A full-scale, quantitative instream flow study, which could be used to recommend a specific habitat-based instream flow, was beyond the scope of the study.

6.22 Description of the Study Area

Below Silver Lake, the river flows through areas of wooded, rural and suburbanized land use. The stream is of relatively low gradient, comprised at low flow of a repeating pattern of relatively uniform shallow runs and riffles, often bordered by wetlands (Photos 1 and 2). At least one stream channel section near the confluence with Jones Brook appears to have been altered by creation of a straightened, bermed embankment (Photo 3). Deep pools are relatively scarce. Substrate is predominantly fines, sand and gravels. Cobble, boulder and ledge substrates are not prevalent. Areas in the lower study area had such low gradient as to be extensively backwatered or impounded and thus dominated by subcritical flow that would not change significantly in suitability across a wide range of discharges.

The fish community was sampled in 1998 by the Massachusetts Division of Marine Fisheries. The resident warmwater fish community was comprised of largemouth bass, bluegill, tessellated darter, yellow perch, redfin pickerel, and chain pickerel. Of these species, only the tessellated darter would be classified as a fluvial specialist, all others would be considered habitat generalists (Bain and Meixler, 2000), *i.e.* not specifically dependent on riverine habitat. White sucker were observed spawning in the study area during spring 2002. Brook trout are currently stocked in the Jones River to support a spring put-and-take sport fishery.

Migratory diadromous species utilize riverine habitat for zone of passage as well as rearing or spawning. Catadromous American eel were detected in the 1998 survey. American eel enter the river and utilize its habitat for nursery habitat prior to emigrating to the sea to spawn. Other anadromous species such as alewives were historically present in the watershed, but do not currently occupy the main stem of the Jones River upstream of the Wapping Road dam.

6.23 Methods

The Jones River was investigated between Silver Lake and the confluence with the Halls Brook subwatershed. The field investigation consisted of a site visit to characterize habitat, identification of specific areas with fluvial habitat where representative habitat and flow characteristics could be obtained, and collection and analysis of habitat and hydraulic information on designated transects.

A site visit was conducted during a period of low flow on September 11, 2001. The stream was walked and waded from Lake Street downstream a distance of approximately 1,000 feet. A hip chain accurate to 1 ft was employed to measure the distance downstream from the starting point of specific points of interest, and habitat stations were located and labeled according to this referenced distance. Because of the uniformity and repeating pattern of the stream channel, a total of three transects were established to account for the predominant riffle, run and run/pool habitat.

At each transect, a benchmark was established, stream bed and water elevations were optically surveyed, and a staff gage was installed for future stream stage reference. Due to the prevailing dry climate conditions and below-normal stream flows, additional instructive flow measurements could not be obtained until April 3, 2002, by which time the staff gages had been displaced. The stream was also gaged on each site visit to estimate the prevailing discharge associated with the observed flow. A stream bed profile was surveyed from the top of bank across the channel to the opposing top of bank, and included verticals at toe of bank, and across the channel at intervals to delineate changes in bed profile, and wetted area. Intervals were referenced along a temporary flexible fiberglass survey tape accurate to 0.1 ft. The transects were revisited on subsequent dates so that additional discharge and water elevation data could be collected.

The stream was also walked and/or waded at publicly accessible locations between Grove Street and the Wapping Road dam. In some cases, landowner permission was required and secured to access areas of potential interest. However, no additional transect data were collected in these stream reaches due to poor indicators of habitat-based flow stress. This was because in one area the stream channel was heavily modified, and appeared to be over widened, and the lower reaches of the study area were backwatered and therefore provided poor indication of habitat changes relative to flow.

Survey data for each cross-section were entered into Microsoft Excel spreadsheet format. Bed profiles were established as X-Y coordinates. The Z-coordinate (depth) was computed based on relationship of water elevation to bed elevation at each flow for which data were available. Water depths not field-measured, but potentially of interest (i.e. corresponding to naturally-occurring August median flow) were simulated using hydraulic modeling as discussed below.

Habitat Suitability (HS) index criteria available for a representative cross-section of the species reported to inhabit the river were obtained and reviewed to characterize the suitability of habitat under prevailing flows (**Appendix I**). These HS criteria are commonly used in mathematical habitat models such as the Physical Habitat Simulation (PHABSIM) (Bovee, *et al*. 1998). The suitability of each of the stream habitat variables of depth, velocity and substrate are uniquely rated for each subject species and lifestage on a scale from 0.0 to 1.0. A rating of 0.0 indicates that unsuitable conditions exist, a rating of 1.0 indicates optimal suitability. For purposes of this assessment, we assigned the following qualitative values to the numeric scale:

H.S value	**Suitability Rating**
0.0	Unsuitable
0.1-0.3	Poor
0.31-0.7	Fair
0.71-0.99	Good
1.0	Optimal

In this study, only the variable of depth was evaluated. This was based on the observation that, at low flows, the river study area was depth-limited, and that given the low gradient, the variable of velocity was not likely to become limiting unless high flow suitability was an issue requiring detailed analysis.

The selection of evaluation species and lifestages is an important part of habitat evaluation. Although there are no absolutes, general guidance can be found in precedent. Bovee, *et al.* (1998) recommend that species and lifestages selected for an instream flow assessment should reflect expressed fishery management objectives, and/or representative species representing use of specific habitats of interest (known as a "guild" approach). Bovee, *et al.* (1998) also suggest that a mix of evaluation species should be used. Further, in New England, the USFWS (1994) states that:

> "*When selecting species for use as evaluation species in IFIM and related studies of water development project, obligate stream (lotic) species or lifestages should be utilized or recommended. Facultative species and/or lifestages should be carefully considered or, in some cases avoided as evaluation elements…. Staff should focus their review and evaluation on the habitat specialists within the stream system such as members of the riffle/run community…*".

This is because not all mesohabitat types are equally susceptible to dewatering effects, and facultative species (i.e. habitat generalists) may not provide an accurate barometer of low-flow habitat protection (Bovee, *et al.*, 1998, Aadland 1993). The scarcity, or potential absence, of riffle dwelling species in this watershed further suggests that obligate riffle/run dwelling species and lifestages should be considered in evaluating habitat and flow. There is also danger of selecting too many species, as this "*may facilitate getting the study started, but will ultimately make the analysis of alternatives more* *difficult*" (Bovee, *et al.*, 1998). Based on these principles, recommended evaluation species and lifestages for this analysis could logically be:

Species	Life stage	basis
Brook trout	juvenile	Contributes to game fishery historic native species
Brook trout	adult	Historic native species lifestage is stocked by MDFW
White sucker	spawning	Spring obligate riffle/run dwelling guild
White sucker	juvenile	Summer-fall obligate riffle/run dwelling guild
tessellated darter	adult	Year round obligate riffle/run dwelling guild
tessellated darter	spawning	Spring obligate riffle/run dwelling guild
Caddisfly or mayfly	larvae	Year round obligate riffle/run dwelling guild

Although white sucker were not formally listed in the fishery survey of the Jones River, they were observed during this study. Further, sucker habitat needs represented by these SI curves may serve as surrogates for other species for which curves are not readily available. The fluvial-oriented lifestages of white sucker, tessellated darter and brook trout were thus selected. White sucker and tessellated darter represent riffle and run guild habitat users, while brook trout reflect a historically occurring high-quality habitat use for a species of potential resource management interest. Macroinvertebrates represent an infauna/epifaunal forage species. Specific SI criteria for tessellated darter, white sucker and macroinvertebrates were obtained from a recent study conducted on a watershed with similar overall biogeography and habitat characteristics (GZA, 2000). Brook trout SI curves were obtained from recent habitat studies conducted in New England (Kleinschmidt Associates, 1994).

The stage-discharge relationship was examined to estimate the rate of change of wetted area among flows. A HEC-RAS computer model (River Analysis System, version 3.0, U.S. Army Corps of Engineers, 2001) was used with the transect information obtained during the field survey. A range of observed and other flows (such as the unregulated August median flow for the Jones River at the USGS gage at Elm Street) were input into the model to obtain estimated values of flow depth, water surface elevations, velocity, wetted perimeter, etc. The results of the model (Appendix I) were compared to field data to check for model reasonability, and the output was subsequently used to investigate habitat suitability for a variety of flows. Discussion of alewife passage is described separately in Section 6.30.

6.24 Results

Distribution of Habitat

The stream reach below Silver Lake was found to have a repeating habitat pattern. This pattern consisted of a meandering, shallow channel, comprised of short riffles, followed by runs and shallow pool/runs both of which were comprised of relatively fine substrates ranging from pea gravel in riffles to sands and silt in runs and pools (Table 6-2).

Cover consisted of off stream overhead canopy and some woody debris. Instream object cover such as boulders was absent.

Discharge Measurements

Data were collected on three transects, T-65, T-380 and T-960 (**Figure 3-6**). Discharge was gaged at station 960 as 0.1 cfs on September 11. The stream was re-gaged on September 18, 2001 and on January 29, 2002 with values of 0.1 and 0.3 cfs, respectively. During a period of what would typically be expected to be high spring flow, the river was gaged on April 3, 2002 showing a discharge of 0.6 cfs. It should be noted that stream flows measurements were taken during consistently dryer than normal precipitation conditions and during periods when Silver Lake was not spilling into the Upper Jones River.

Habitat Suitability

Habitat suitability was compared for each transect at the observed low, dry summer flow (approximately 0.1 cfs) at the observed flow of 0.6 cfs (0.15 cfsm, likely more indicative of a low summer base flow), and at a flow estimated as equivalent to the August median flow, as estimated from the USGS gage at Elm Street, if the Upper Jones River flow was unregulated (i.e. experiencing a natural hydrologic flow regime, without the presence of Forge Pond Dam).

Station T-65

Figure 6-1 illustrates the bed profiles providing habitat in riffle mesohabitat channel types represented by T-65, and displays relative wetted area and depths occurring at 0.6 cfs. No data were available at 0.1 cfs.

The stream channel here is a relatively narrow incised riffle, with a well-defined thalweg. At a flow of 0.6 cfs, wetted channel width was approximately four feet, and depth ranged from 0.03 ft to 0.24 ft. Habitat suitability was rated as poor to fair for most species and lifestages other than brook trout and macroinvertebrates for which habitat was rated as unsuitable based on the criteria (Table 6-3a). A discharge approximating the unregulated August median flow increases wetted width and improves depth suitability for most species and lifestages other than brook trout which remain depth-limited (Table 6-3b). Juvenile brook trout habitat increases somewhat from unsuitable to poor/fair, most other lifestages realize good to optimal depths at this discharge.

Station T-380

Figure 6-2 illustrates the bed profiles providing habitat in run-pool mesohabitat channel types, and displays relative wetted area and depths occurring at three flows. At a flow of 0.1 cfs, discharge was sufficient to minimally wet only the channel thalweg, and typically only to a depth of approximately 0.1 ft. These depths were too shallow to provide even nominal habitat in the run/pools represented by transect 380 (Table 6-4a). At a flow of 0.6 cfs, approximately the same wetted area was available, however, typical depth increased to 0.2 ft to 0.3 ft, and habitat suitability increased for most species and lifestages other than adult brook trout and macroinvertebrates. (Table 6-4b). A discharge approximating the unregulated August median flow increases wetted width and improves depth suitability for most species and lifestages other than adult brook trout, which remain depth-limited (Table 6-4c). Most other lifestages realize good to optimal depths at this discharge.

Station T-960

Figure 6-3 illustrates the bed profiles providing habitat in a run-riffle mesohabitat channel with a more pronounced thalweg, and displays relative wetted area and depths occurring at both 0.1 and 0.6 cfs. At a flow of 0.1 cfs, the wetted area represented by transect 960 was limited only to the channel thalweg. However, the stream channel geometry provided depths ranging up to 0.2 ft and 0.3 ft in places. Such depths provide unsuitable to fair habitat suitability (Table 6-5a). At a flow of 0.6 cfs, wetted area increased as depth increased to 0.4 to 0.5 ft. flooded the stream bottom adjacent to the thalweg. Habitat suitability of the thalweg improved to fair to good (Table 6-5b). Species that gained relatively little significant increase in suitability were brook trout and macroinvertebrates. Species and lifestages that gained significant areas of good or optimal habitat included fry and juvenile white sucker, and tessellated darter. A discharge approximating the unregulated August median flow increases wetted width and improves depth suitability for most species and lifestages other than brook trout, which remain depth-limited (Table 6-5c). Most other lifestages realize good to optimal depths at this discharge.

6.25 Discussion

We conclude the following from the data:

- Habitat suitability and wetted area both increased between 0.1, 0.6 and 2.1 cfs (unregulated August median flow). Gains were most pronounced in run/riffle habitat represented by T-960, and were least pronounced in riffle habitat such as that represented by T-65. This is most likely due to the slightly lower gradient channel slope existing in runs that result in hydraulically robust conditions. In robust conditions, depth (and thus wetted area) increases at a faster rate than velocity as more water is added. Conversely in low-robust conditions such as riffles, velocity increases more rapidly than depth (and thus wetted area) so that significant increases in discharge are required to experience increased depth in riffles (Bovee, 1992).

- Stream flows ranging down toward 0.1 cfs provide relatively unsuitable physical habitat for a cross-section of representative species and lifestages reviewed in this analysis. Flows ranging toward 0.6 cfs improve wetted area and habitat suitability, but do not necessarily provide good or optimal habitat as depths remained typically at the unsuitable and poor range.

- An unregulated August median discharge is commonly cited as a naturally occurring low flow capable of sustaining an aquatic riverine community without undue stress (USFWS 1994). August is typically the lowest flow period in the annual hydrologic cycle in New England, and most stream ecosystems have adapted to survive in the habitat conditions that prevail under those conditions. This flow is frequently referred to as the Aquatic Base Flow (ABF) (Instream Flow Council, 2002). Habitat suitability and wetted area increased at the August Median flow, with a significant increase in the suitability of depths for most species and lifestages into the fair to good range.

- This analysis is limited to a relatively coarse comparison of habitat suitability at the existing low flow below Silver Lake with the ABF (one common regulatory benchmark), which for purposes of this analysis was synthesized for this watershed. It is possible that alternate flow targets to this particular standard may be appropriate for habitat conservation in this segment of the Jones River. A more quantitative and predictive analysis such as a Physical Habitat Simulation (PHABSIM) model may be appropriate to more precisely target a flow range that is suitable for aquatic habitat and balances of stream water use (Bovee, *et al*. 1998).

- Seasonal varying flows are desirable. Certain lifestages, such as spawning, occur during spring, and require flows sufficiently high to inundate riffles, which is where the species evaluated in this analysis spawn (Scott and Crossman 1973, Smith 1985). Other functions of high spring flows are to distribute nutrients to and from the flood plain, provide connectivity for migrants and to maintain channel characteristics (Dunne and Leopold 1978). On a typical unregulated stream in southern New England, such seasonal high flows would be expected to occur naturally during March and April.

- The focus of this investigation was the Upper Jones River, below Forge Pond Dam. This reach was selected for analysis as a result of its reported lower than expected stream flows and based upon site reconnaissance and professional judgment. The other portions of the Jones River watershed, based upon the inflow/outflow analysis presented in Section 5.0 and field observations, are anticipated to experience substantially higher base flows and total stream flows, which is an indication of more suitable aquatic habitat.

6.30 IN-STREAM FLOW RECOMMENDATIONS

A set of criteria which is generally applicable to the watershed is the U.S. Fish and Wildlife Service Aquatic Baseflow Policy (USFWS ABF). The New England Flow Policy was developed in 1981 as a water resources regulatory and planning tool for use by government agencies and others involved in water resources management. The following background for the Policy is presented by the USFWS in the Interim Regional Policy document:

> "The USFWS has used historical flow records for New England to describe stream flow conditions that will sustain and perpetuate indigenous aquatic fauna. Low flow conditions occurring in August typically result in the most metabolic stress to aquatic organisms, due to high water temperatures and diminished living space, dissolved oxygen, and food supply. Over the long term, stream flora and fauna have evolved to survive these periodic adversities with[out] major population changes. The USFWS has therefore designated the median flow for August as the Aquatic Base Flow (ABF). The USFWS has assumed that the ABF will be adequate throughout the year, unless additional flow releases are necessary for fish spawning and incubation. We have determined that flow releases equivalent to historical median flows during the spawning and incubation periods will protect critical reproductive functions."[36]

The document goes on to state the USFWS personnel shall "recommend that the <u>instantaneous</u> flow releases for each water development project be sufficient to sustain indigenous aquatic organisms throughout the year." The following flow recommendations, generated from stream gage analyses of several gaged watersheds (i.e., "sample watersheds") throughout New England, are presented in the Policy, and have also been endorsed by the Massachusetts Division of Fisheries and Wildlife for use in the absence of site-specific data, as is the case for the sub-basins of the Jones River watershed.[37]

(a) 0.5 cfsm for June to October,
(b) 1.0 cfsm for October to March,
(c) 4.0 cfsm for March to April,
(d) 1.0 cfsm for May and June.

The USFWS ABF recommendations must be carefully considered however. In a 1990 paper in the journal *Rivers*, Kulik states, "There has been a growing concern among water users and resource managers that the 0.5 cfsm value may not be a universally applicable approximation of unregulated median August flow in all New England streams."[38] When implementing the USFWS method, there are several important criteria used in the selection of streams for the calculation of the ABF, including: 1) essentially unregulated stream; 2) minimum drainage area of 50 square miles; 3) minimum period of record on stream gage of 25 years; and 4) good or excellent quality gage data. The Jones River watershed would not have met these criteria and therefore may differ from the sample watersheds in important ways. In addition, the USFWS sample set was taken from all over New England while it has been shown that Massachusetts median August streamflows differ significantly from the 0.5 cfsm used in the USFWS ABF policy. According to USGS data, "The statewide median of the August median streamflow was 0.246 cubic foot per square mile (cfsm); however the median in the western region was

[36] U.S. Fish and Wildlife Service. Interim Regional Policy for New England Stream Flow Recommendations. Newton Corner, MA. 1981.
[37] Mass. Division of Fish and Wildlife. Todd Allan Richards, Personal Correspondence, Sept. 25, 2000
[38] Kulik, Brandon H. A Method to Refine the New England Aquatic Base Flow Policy. "Rivers" Vol.1 No. 1. pp 8-22. 1990.

0.271 cfsm and the median in the eastern region was 0.197 cfsm. A third hydrologic region, the southeast coastal region, encompasses an area in which surficial geology is entirely stratified drift, and for which data were insufficient to determine August median streamflows."[39] The August median flow rate for the Jones River, as calculated from the USGS stream gage at Elm Street, is about 0.7 cfsm.

The recommended flow rates are referred to as streamflow; however, they represent instantaneous flow rates. Therefore, in the relatively small Jones River watershed, baseflow values are likely to be a more accurate indicator of typical instantaneous flow rates in the dry summer months. Note the median August flow values used in this report are actual monthly median values, and not a median of monthly mean flows that is used in the USFWS ABF policy.

Massachusetts Water Resources Commission flow recommendations for the Jones River at Elm Street (Appendix J) closely resemble the USFWS ABF flow targets (i.e., 0.51 cfsm year-round and 3.02 cfsm for March 1 to May 15). DEM's 1991 South Coastal Basin plan contains these flow recommendations and also recommended year-round minimum instantaneous flows for Pine Brook of 1 MGD (1.55 cfs or 0.32 cfsm). This recommendation, while lower than the USFWS target, approximates the estimated natural baseflow for Pine Brook.

Table 6-6 indicates the total recommended minimum in-stream flows for each of the subbasins in the watershed, which result from a modification of the USFWS ABF New England Flow Policy, in the absence of continuous flow data with which to calibrate and verify our subbasin water budget results. One change was made from the USFWS recommendations: the March-April "bankfull" discharge is approximated as 4 cfsm. However, the water budget predicts spring flows of between 1.4 cfsm to 6.7 cfsm for the subbasins and the USGS gage at Elm Street has historically averaged about 3.2 cfsm during the month of April. Considering the data, GZA has recommended a watershed-wide target discharge for March-April of 3.2 cfsm. The recommended flow criterion for the watershed and its subbasins therefore becomes:

(a) 0.5 cfsm for June to October,
(b) 1.0 cfsm for October to March,
(c) 3.2 cfsm for March to April,
(d) 1.0 cfsm for May and June.

These flow criteria listed above are general recommendations for use in the area of the Jones River watershed. The proximity of the August median streamflow of 0.7 cfsm in the watershed to the 0.5 cfsm summer-flow recommendation of the USFWS seem to generally support the use of USFWS recommendations in the watershed. To develop more specific recommendations for the individual streams and rivers of the subbasins, it is necessary to either verify the subbasin water budget results with continuous, long term flow data, or to

[39] U.S. Geological Survey. August Median Streamflows in Massachusetts. Water-Resources Investigations Report 97-4190. Kernell G. Ries III. 1997.

conduct detailed stream-specific evaluations (i.e., IFIM/PHABSIM analyses), which are beyond the scope of this study.

In the future, additional study may lead to site-specific flow targets based on stream-specific evaluations and the data contained herein. Setting of flow goals is also a function of competing stakeholder values and, ultimately, consensus. The information in Appendix J provides a range of potential target flows derived from USFWS recommendations, WRC recommendations, and GZA water budget results that may support future flow target modifications.

When comparing USFWS flow targets to the results of our inflow / outflow analysis, it should be remembered that the water budget model produced by GZA estimates monthly average flows for both the baseflow component of streamflow and for total streamflow. Monthly averages are not the same as monthly median values, and at times may be quite different. This is particularly true in a relatively small watershed where surface water flows pass quickly through the system during periods when base flow is low. An example of this can be found in the Jones River: The median August flow rate is 0.7 cfsm, while the mean August flow rate is 1.04 cfsm. A second example is provided by another somewhat similar river, the Indian Head River in Hanover. The median August flow rate in the Indian Head River is 11.0 cfs (0.36 cfsm) while the mean August flow rate is 22.2 cfs (0.73 cfsm). Monitoring of flows within a stream may either concentrate on statistical analysis of a data set compiled over a certain time period (e.g. monthly) composed of numerous, more frequent flow measurements (e.g. daily or continuous), or on individual instantaneous flow rates. Both approaches have advantages and disadvantages. The primary constraint on using a statistical approach is that a significant amount of data must be collected and reduced. As such, GZA has chosen to consider both monthly average streamflows and instantaneous streamflows in our analysis of habitat availability during the low-flow period of the year.

The water budget model created by GZA for this study estimates two flow values: 1) Average Monthly Baseflow, and 2) Average Monthly Streamflow (of which baseflow is a component). The later value, average monthly streamflow, may be directly compared to flow data from the streams and rivers of the Jones River, provided that enough measurements are collected to form a statistically significant data set. Average monthly streamflow is not, in GZA's opinion, a good indicator of what the typical instantaneous streamflows are likely to be. This is because the average or mean monthly streamflow takes into account both periods of high and low flow. And, as shown above, the average monthly streamflow is not, in GZA's opinion, a good indicator of median monthly streamflow, particularly in the summer.

It is GZA's opinion that that average monthly baseflow value predicted by the water budget model is more representative of the median monthly streamflow in the Jones River watershed. This is because during summer months when effective precipitation is at its lowest, streamflow will be comprised primarily of groundwater outflow (i.e. baseflow) for the majority of the time; however, rain events such as thunderstorms can produce high intensity, short duration runoff which may account for a significant portion of streamflow quantity when averaged over the month. For the purposes of evaluating aquatic habitat, total amount of flow in the channel is the important parameter – regardless of whether the flow originates from groundwater outflow or surface runoff. The important issue is to establish the appropriate and representative quantity of total streamflow. In GZA's opinion, the flow rate associated with baseflow is more representative of typical (i.e. median) flow rates during summer low-flow periods than the average monthly total streamflow rate estimated by the water budget model.

Therefore, for the summer low-flow periods, GZA recommends evaluating habitats using streamflow rate equivalent to the baseflow value predicted by the water balance discussed above. The USFWS New England Flow Policy states that "Aquatic Base Flow as used here should not be confused with the hydrologic base flow, which usually refers to the minimum discharge over a specified period." However, it is also very specific that the flow recommendations apply to <u>instantaneous</u> flow releases. It is GZA's opinion that the water budget-derived baseflow value is a better indicator of typical instantaneous flow (i.e. median streamflow) in the streams and rivers of the watershed during the summer months.

<u>Alewife Passage / Flow Recommendations</u>

The alewife (*Alosa pseudoharengus*) is an anadromous fish native to the Jones River. Their use of the river is seasonal. Adults grow to maturity at sea, and ascend Massachusetts rivers to spawn during the spring typically following the falling limb of the spring run-off hydrograph, and as water temperature rises (Bigelow and Schroeder 1953). Squiers (1988) reports spawning as occurring at temperatures of 55-60^{o}F. Its body length is generally one third deep as long; spawning adults are generally 11-12 in. long and weight approximately ½ pound (Squiers 1988).

Squiers (1988) states that up to 25 percent of the spawning run may be comprised of repeat spawners. Spawning occurs in ponds and lakes; surviving spent adults make their way downstream to tide water immediately after spawning. Eggs incubate and hatch into fry after three days, and the young fish remain in the nursery habitat until late summer when the seaward migration begins, and may extend through November. The juvenile fish may range in length from 1.25 to six inches in length depending on the fertility of the nursery waters, competition, and length of time at large in the lake after hatching (Squiers 1988). Juveniles remain at sea until reaching sexual maturity, at which time the return to their natal watershed to spawn.

Because alewives are seasonal visitors to the watershed, and require lentic habitat for spawning, the primary importance of stream flow to the species is as a migration corridor to provide connectivity (Bovee, *et al.* 1998) between tidewater and spawning/nursery areas.

According to the Jones River Watershed Association, alewives "*migrate and spawn above the Elm Street dam. The run is above the dam and up Furnace/Trout Brook to Soules Pond ultimately to Sylvia Place and Russell Ponds. Adult alewife were observed in 2002 both going upstream and returning over the dam… many alewives are stranded in Silver Lake having been apparently diverted there from Furnace Pond and the North River Herring Brook run*."

The common way that low flows may affect the migration is primarily by creating migratory obstructions. This can result if a lack of flushing flows have allowed debris to accumulate excessively in stream channels or permitted build-up of vegetation and/or geologic bars in channel areas which channel forming flows would normally keep open (Dunn and Leopold, 1978; Poff, et al., 1997), and/or low flows result in inadequate hydraulic depths to facilitate zone of passage (Bovee, *et al*.1998, Bovee 1982) in a reach deemed critical for passage for the successful continuation of the species' productivity throughout the system.

Although site-specific hydraulic data were not gathered in this study that can address the site-specific issue of migration access in the lowermost stream reaches connecting to the ponds of the Furnace Brook sub-watershed (i.e., at individual fish ladders, etc.), there is potential for future restoration of a run of alewives to be spawned in Silver Lake. Data collected at transect 960, located downstream from the Forge Pond Dam provides insight to this issue, and in general can be considered representative of much of the riffle/run habitat in the watershed. As discussed previously, this transect is representative of channel slope and morphology in this stream reach through which adult alewife would need to ascend to reach Silver Lake during May, and potentially descend following spawning (May-June). Young of year (YOY) would need to descend this reach primarily in October-November. Figure 6-4 illustrates the projected mean depth at the transect as a function of flow. The data show that a flow of 0.6 cfs is required to produce a wetted channel depth of 0.3 ft (4 inches) and a flow of 2 cfs provides a depth of 0.5 ft (6 inches).

Bovee (1992) recommends as a rule of thumb, a minimum water depth criterion of 2/3 body depth of the targeted fish requiring passage at the point of interest in the stream across at least 25 percent, but that this should be tempered

> "*by the number and length of crossing the fish must make. Fish that encounter very few passage barriers can probably negotiate some fairly shallow water. The same species moving up a stream with many passage bars may arrive at the spawning area in poor condition if the passage depths are minimal*"

Using these criteria, for adult alewives (typical body depth of 4 inches) a reasonable minimum depth target of 2.6 inches should be maintained during the May-June instream migration season. For YOY passage in the fall (body depth 2 inches), a minimum water depth target of 1.3 inches is recommended. Thus, assuming that there are relatively few obstructions, a minimum flow of about 0.5 cfs (about 0.12 cfsm from the Silver Lake watershed) from the Forge Pond Dam should be provided during the critical months that satisfies this requirement. Note that the flow recommendations provided previously (i.e., 0.5 cfsm for the Summer/Fall and 1.0 cfsm for May/June) exceed this standard, and are preferred for the watershed as a whole.

6.40 AQUATIC HABITAT SAFE YIELD ESTIMATES

Safe Yield is a hydrologic term with several different meanings. When used in discussions of reservoirs and water supply systems, *Safe Yield* is defined as, "The maximum quantity of water which can be guaranteed during a critical dry period."[40] When referring to groundwater, *Safe Yield* is said to "Express the quantity of water which can be withdrawn without impairing the aquifer as a water source [i.e. irreversible depletion of storage], causing contamination, or creating economic problems from a severely increased pumping lift."[41] Safe Yield may be expressed in terms of million gallons per day (MGD), which is a convenient term, particularly because DEP registrations and permits refer to average daily demand (ADD) in terms of MGD.

For the purposes of this study, GZA has coined the term *"Aquatic Habitat Safe Yield"*, which we defined as being the maximum quantity of water which may be withdrawn under given hydrologic conditions which will allow average annual in-stream flows to remain at or above the specified seasonal minimums to conserve, restore, and manage sustainable fish and wildlife populations. In other words, Aquatic Habitat Safe Yield is used as an estimate of how much demand may be supported by the watershed without reducing streamflows below the target flows presented earlier. **Aquatic Habitat Safe Yield is not an indication of the available drinking water volume in a particular basin**.

The potential Aquatic Habitat Safe Yield of each subbasin was evaluated individually. It was assumed that minimum flows must be maintained in each subbasin. Therefore, each subbasin could be and was evaluated separately, without regard to upstream or downstream subbasins. Subbasins were assessed for maximum amount of water withdrawal possible while maintaining minimum seasonal streamflows. Since remaining streamflows after water withdrawals were adequate on a per square mile basis, flows from one subbasin to the next did not create either a surplus or deficit in streamflow. It is important to note that the estimates of Aquatic Habitat Safe Yield do not account for the specific locations of wells or diversions within the watershed and the maximum yield available to these withdrawal points. The infrastructure needed to utilize the maximum groundwater and/or surface water available from all sub-basins does not exist (due to well inefficiencies, etc.); therefore the Aquatic Habitat Safe Yield estimated in this report may be higher than is currently feasible. It should also be noted that the estimated Aquatic Habitat Safe Yield considers the entirety of subbasin drainage area. In other words, the estimated Aquatic Habitat Safe Yield should be considered valid at the outlet of the specific subbasin, and withdrawing any volume of water from the watershed may deplete streamflows, regardless

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[40] Linsley, R.K. and Franzini, J.B. Water-Resources Engineering. McGraw-Hill. 1964.
[41] ibid

of whether or not the withdrawal meets the guidelines of the Aquatic Habitat Safe Yield. The Aquatic Habitat Safe Yield can be likened to a “screening tool,” capable of providing preliminary information on a sub-watershed-wide basis, but in no way substituting for site specific analysis.

The Aquatic Habitat Safe Yield for each subbasin was estimated in each month by estimating the amount of streamflow available in excess of the recommended average target flow. The quantity of water to remain in the stream was subtracted from the average monthly streamflow under virgin conditions to estimate the potential maximum volume of water available for withdrawal:

$$\mathbf{Q_{natural} - Q_{rec} = Q_{avail}}$$

Where:

$\mathbf{Q_{natural}}$ = Natural total streamflow (baseflow + runoff)

$\mathbf{Q_{rec}}$ = Recommended Average Streamflow for aquatic habitat

$\mathbf{Q_{avail}}$ = Aquatic Habitat Safe Yield

Thus all streamflow in excess of the seasonal recommended minimum for that month is assumed to be available for withdrawal. Withdrawals may be either from surface water diversion or via groundwater pumping, which would affect streamflow through baseflow reduction. The Aquatic Habitat Safe Yield calculations have been made on the basis of a year with average precipitation and evaporation rates.

Table 6-7 presents the monthly Aquatic Habitat Safe Yield estimates for each subbasin. Note that the tidal subbasin and Silver Lake have been excluded from the summary calculations.

Except for Brockton’s withdrawals from Silver Lake, current levels of withdrawals from the watershed (seasonally as high as 5.2 MGD) do not exceed the estimated Aquatic Habitat Safe Yield of the watershed (17.53 MGD) on an annual or seasonal basis. However, because withdrawals are concentrated in certain sub-basins rather than spread evenly across the whole watershed, impacts may be disproportionate on some streams. In addition, some of the subbasins, Pine Brook in particular, are predicted to have stream flows below watershed flow recommendations, even under natural conditions. Seasonal average withdrawals (including cranberry bog estimated consumptive usage and excluding Silver Lake withdrawals) were compared by GZA to seasonal average safe yields below:

Period	For entire Jones River watershed (except Silver Lake): Seasonal AHSY		Ave. Seasonal Withdrawal
July 1 to September 30	11.47 MGD	>	5.19 MGD
October 1 to February 28	19.95 MGD	>	1.76 MGD
March 1 to April 30	11.62 MGD	>	2.00 MGD
May 1 to June 30	26.48 MGD	>	4.53 MGD
Average Annual	17.53 MGD	>	3.37 MGD

As previously discussed, the water balance evaluation for Silver Lake was developed in a different manner from the balance of the Jones River watershed. Accordingly, the Aquatic Habitat Safe Yield from Silver Lake was also estimated in a different manner. In this subbasin, surface water storage in the Lake is important. Using the lake water budget model under natural conditions, an iterative process was undertaken to estimate the amount of withdrawals from the Lake which would hypothetically result in an average flow downstream of 0.5 cfsm. This exercise indicated that 5.25 MGD of withdrawals from the lake would maintain an annual average of 0.5 cfsm (about 2.0 cfs) of flow downstream. Restricting the minimum flow criteria to only the month of August (i.e., iterate withdrawals to produce an August average flowrate of 0.5 cfsm), the maximum withdrawals must be only 0.6 MGD. This is due to the natural hydrology of the watershed, wherein the elevation of Silver Lake reaches its natural low in the month of August. In fact, under natural conditions, the outflow from the Lake during August is estimated to be 0.74 cfsm (about 3 cfs), which does not leave much flexibility in maintaining lake elevations to provide constant spillway discharge.

The estimates above are each lower than the reported traditional Safe Yield estimate reported in Section 4.40 for a variety of reasons. First, as discussed earlier, traditional safe yield does not consider potential downstream environmental impacts (i.e., downstream releases for fisheries) and is only a reflection of the volume of water that may be withdrawn without permanent depletion of storage. Second, the traditional safe yield number takes into account the diversions from Furnace Pond and Monponsett Pond. However, the contributory watersheds for Furnace and Monponsett Ponds were not considered as part of the Aquatic Habitat Safe Yield analysis because the diversions from these basins are allowed only from October through May. Since the critical flow periods, as well as potential severe drought conditions, occur during the period between June and September, it is GZA's opinion that the safe yield of Silver Lake consider only the year-round contributory drainage area of 4.09 sq.mi. Nevertheless, the reliable drinking water supply yield that can be obtained from Silver Lake is expected to be far greater than the 0.6 MGD estimated as the Aquatic Habitat Safe Yield.

Projected 2020 levels of withdrawals from the entire watershed do not exceed the estimated Aquatic Habitat Safe Yield of the watershed. The exceptions to this are Silver Lake and Pine Brook. This suggests that flows in some or all of the tributaries of the Pine Brook watershed and downstream of Silver Lake are likely to fall below the recommended minimum instantaneous in-stream flow threshold during at least a portion of the year. It should be remembered, however, that the water budget indicates USFWS flow recommendations are not met even if one could revert back to a natural condition in the Pine Brook subbasin.

It is important to note the Aquatic Habitat Safe Yield can be a moving target, depending on the set of target flows in the basin. Realistically, the selection of target flows is as much a political / watershed management decision as much as it is a scientific issue. To provide some additional context on this issue, GZA has assembled a range of Aquatic Habitat Safe Yield estimates for the recommended USFWS flow criteria, as well as other flow goals that may be used to gage the sensitivity of the AHSY with the target flow in the subbasins (**Appendix J**).

Once again, it must be noted that the Aquatic Habitat Safe Yield estimated by this study does not refer to physical capability of supply systems to actually withdraw water from the watershed. No long-term operations study or simulation was undertaken to estimate reliability of the systems to meet demand; nor were the capacities of individual wells, pumps, treatment plants, or storage tanks taken into account.

Several potential courses of action might be considered to restore the aquatic habitat to desirable levels in affected stream reaches while at the same time meeting the water supply needs of the community. One alternative is to reduce demand via consumer education, improvements in efficiency, changes to water cost structure, etc. A second alternative is to find new sources of water either in locations within the watershed where impacts are not critical, or from outside the watershed altogether. It is also possible that modifications to the operational strategies of the water utilities/suppliers might help mitigate the problems. Changes in the timing of withdrawals from surface water sources such as Silver Lake might help to keep instantaneous flows higher during the critical summer months. The development of alternate water sources for the City of Brockton, in particular the development of the proposed Bluestone desalination project, may also help to alleviate the pressure on Silver Lake.

6.50 CONSERVATION MEASURES

6.51 Current Practices

The following information is a review of current water use and conservation practices of significant municipalities which withdraw water from the Jones River watershed (i.e., Brockton, Kingston). Information is also provided for the Towns of Pembroke and Duxbury, each of which have at least one water supply withdrawal within the watershed The information was taken from DEP Public Water Supply Annual Statistical Reports from 1996 to 2000 and from discussions with local water supply officials.

Brockton

Between 1996 and 2000 total water consumption by the City of Brockton decreased by 15 percent (by volume) with the largest annual drop (16 percent) between 1996 and 1997. Table 6-8 shows that there was a large decrease in unaccounted for water between 1996 and 1997 (from 15 percent to 6 percent). However, unaccounted for water has been increasing gradually from a low of 2 percent in 1998 back up to 7 percent in 2000. The Town's annual leak detection program was continued beyond 2001 to attempt to remedy the problem with increasing unaccounted for water volumes (Brockton has reduced the annual volume lost through leakage from 500 MG to 26 MG). Brockton has also instituted increasing block water rates which can encourage water conservation. Water conservation tips and water saving messages were sent out to customers last year and mandatory restrictions on outside water use between 7am and 9am and 5pm and 7pm Wednesdays, Saturdays and Sundays were imposed.

Kingston

Over the period 1996 to 2000 total annual water consumption by the Town of Kingston increased by only 2 percent (by volume), but fluctuated from a low of 427 MG in 1998 to a high of 487 MG in 1999 (an increase of 14 percent) (Table 6-9). Over the same period, residential water consumption dropped by 34 percent, mostly between 1997 and 1998. There was also a 35 percent increase in water volumes used for commercial purposes over the period between 1996 and 1999, although data for 2000 show that this volume dropped by 15 percent between 1999 and 2000.

Unaccounted for water increased from single digits in 1996 and 1997 to 18 percent in 1999 and 2000 (Table 6-9). According to the Public Water Supply Annual Statistical Reports, the Town has been implementing plans such as leak detection to reduce the amount lost through leaks, fire protection, street cleaning, etc. The Town's leak detection program has been made an annual program and new leak detection equipment was purchased in 1999. In addition, water conservation tips or water saving messages were reportedly sent out to customers last year. Bylaws imposing mandatory restrictions on outside water use are also in place.

Pembroke

The Town of Pembroke has water supplies both in and out of the Jones River watershed. Overall water consumption in Pembroke appears to be increasing gradually, with more water being used for residential and commercial purposes. The volume of unaccounted for water decreased from 90 MG to 53 MG between 1996 and 1998. The Town plans to continue leak detection and meter calibration programs and impose fines on users found to be obtaining unmetered water. The Town also had the fire department monitor the volume of water they used.

Duxbury

After an 18 percent increase in water consumption in Duxbury between 1996 and 1997, the level of water use has stabilized and appears to be declining. The volume of water consumed in 2000 was less than that used in 1996, reflecting the decrease in residential water consumption and ‘other’ water uses. The Town has been attempting to decrease the water volumes lost through leaks by surveying the system every 2 years. In 1998 it was suggested that the survey be carried out every year, but that idea appears to have been phased out by 1999 and the 2 year survey re-instituted. Meter calibrations are also conducted every 2 years, or as necessary. Mailings suggesting conservation tips were sent out to customers with their bills in 2000 and voluntary bylaws restricting outside water use are in place and were used in 1999.

Water Withdrawal Permit Conditions

Each new location of water withdrawal, or increase of water withdrawal at an existing source by 100,000 gpd or more, requires a permit from MA DEP which specifies permitted withdrawal volumes and additional measures that must be undertaken to ensure efficient use of the water. These conditions are reviewed every 5 years. For example, in 1999 the withdrawal permit for Trackle Pond Well was issued to the Town of Kingston subject to the following provisions:

1. Public Water Suppliers must have an ongoing program to test all meters over 10 years old with funds included in the annual water department budget to recalibrate, repair or replace meters as needed.
2. All public Water suppliers must institute a program to survey the entire system for leaks within 2 years of receiving this permit and conduct a full survey biennially (every 2 years) thereafter.
3. Suppliers must have their repair reports available for inspection by the department.
4. Suppliers shall take steps to ensure that the water supply system operations are fully funded by water supply system revenues. The pricing system should reflect the full cost of supplying water, not limited to:
    i. administration costs;
    ii. staff salaries, benefits and insurance costs;
    iii. distribution system operation, maintenance and repair;
    iv. pumping and utilities costs;
    v. treatment costs;
    vi. capital replacement costs;
    vii. costs associated with water conservation programs and public education programs;
    viii. watershed or wellhead purchase and/or protection costs and land acquisition; and
    ix. emergency planning.

5. Public water suppliers must ensure enforcement of the plumbing code for new construction and building rehabilitation where installation of water saving devices and low flow toilets are required.
6. Public buildings must be retro-fitted with water-saving devices (faucet aerators, low-flow showerheads and toilets etc.)
7. If residential consumption is over 80 gallons per capita per day, a program must be implemented to make retrofit devices (faucet aerators, toilet displacement dams etc) available to customers at cost.
8. Suppliers are to develop and implement an education program which emphasizes:
    i. all the costs of providing water;
    ii. that investments in efficiency and conservation will provide consumers with long-term savings; and
    iii. the environmental benefits of reducing water demand.
9. Bill stuffers with conservation tips should be included at least annually with customers bills or as a separate mailing.
10. Outdoor Water Use: The department requires the adoption of a Water Use Restriction Bylaw within 2 years of the issuance of the permit, to include restrictions from odd-even lawn water schedules, to a complete ban on outdoor water use. This should be coupled with an aggressive local education campaign to make consumers aware of the restriction and the penalties for violation and knowledgeable about the need for water conservation.

Similar conditions were attached to permits issued to the Towns of Pembroke and Duxbury, with the exclusions of Number 4, 7 and 8 for Pembroke and Number 10 for Duxbury. In addition, Duxbury was required to monitor and account for water used from fire hydrants and annual flushing programs.

6.52 Recommendations For Water Conservation

Water conservation is the most cost-effective and environmentally sound way to reduce demand for water. The information provided below is a summary of possible techniques appropriate as part of a comprehensive water conservation program. To be most effective, a water conservation program will require each of the water-withdrawing towns in the watershed to coordinate on water policy. Generally, water conservation methods are most effective if a low-water use alternative is made available or publicized that is comparable in cost and does not require any major changes in habit.

Based on the information on water use reviewed above, the priority sectors for water conservation in the Jones River Watershed are residential consumption and commercial consumption.

Reducing Residential Water Consumption (In-home measures)

Data from the American Water Works Association shows that by installing water conservation devices inside the home, water consumption can be reduced by up to

32 percent. Considering the total withdrawals in the watershed of 14.8 MGD, application of an efficient water conservation program could save up to approximately 4.7 MGD per year, assuming no conservation measures are currently in place. The following is a typical procedure for reducing in-home water consumption:

1. Ensure that local bylaws support water conservation:
   Review existing bylaws to ensure that they do not promote unnecessary water consumption;

2. Promote the idea of water conservation throughout the watershed:
   Following the decision to implement a water conservation program, the main challenge to overcome is changing people's habits. The first part of this is education about the benefits of reducing water use. For example, New Englanders often find it hard to believe that there is insufficient water because of the amount of rain that falls in an average year. Education through the media or through schools can often be effective as a first step.

3. Conduct water conservation audits:
   Publicized by and running parallel to the education program, many cities have made water conservation audits easily available (e.g. by making evening and weekend audit appointments available in addition to regular working days). In some cities, these are free and provide customers with the opportunity to get free low flow-showerheads, faucet aerators, and hose nozzle heads installed, plus home-specific advice about further conservation measures that may be appropriate.

4. Implement programs to facilitate exchange of conventional fixtures for low-flow fixtures.

Reducing Commercial Water Consumption

Commercial water users should be strongly encouraged to evaluate their water use practices for areas of potential improvement. While water consumption within this sector varies from one enterprise to another, water is mostly used for purposes such as cleaning and sanitation, cooling and heating, plumbing and landscape irrigation. Due to the nature of commercial buildings and their use, the majority of water savings can be brought about by changes such as:

- Retrofitting sanitary plumbing fixtures (low-flow toilets, faucets etc) and checking for leaks
- Designing irrigation systems to maximize watering efficiency and avoid unnecessary watering
- Capturing, holding and using rainwater for irrigation
- Using Xeriscaping techniques (plants and grass species native to the area and therefore adapted to the local climate) for landscaping

- Parking lot and/or interstate median adaptations to minimize stormwater runoff to municipal drains and redirect runoff to water planting beds and grassy swales
- Changes to practices in particular commercial businesses
  Examining commercial business types for potential water savings can lead to changes in practice and implementation of money and water saving devices. Effective metering allows easy monitoring of businesses that use large amounts of water.

Reducing Outdoor Water Consumption

Targeting outdoor water use habits for residential and commercial properties with large lawns for education programs could result in significant water savings within the Jones River Watershed. Additional savings can be made by applying these techniques to public landscaped areas such as parks. Other options for encouraging water conservation outdoors includes raising water rates (and instituting tariff/reward systems for water conservation), implementing local ordinances aimed at reducing lawn over-watering, and/or requiring new developments to submit plans with water-wise design elements.

Lawn Watering Techniques:

- Promotion of optimum irrigation schedules can result in reduced water usage
- Most lawns only need watering once or twice a week, once they have adapted to less water.
- Once inch of water on the lawn is sufficient for 1-2 weeks
- The optimum time of day to water lawns to get maximum irrigation benefits is before or at dawn or after dark.
- Drip systems are much more efficient (and often cheaper) than sprinkler systems, where much water is lost to evaporation and runoff.

Xeriscaping: using plants native to the Northeast (and therefore adapted to rainfall patterns), using plants appropriate to the soil conditions, using efficient irrigation techniques is becoming more popular. These techniques have been shown to result in water savings of up to 50 percent compared with conventional landscaping practices and also result in water quality benefits due to reduced need for chemical fertilizers.

7.00 CONCLUSIONS AND RECOMMENDATIONS

7.10 GENERAL FINDINGS

The hydrology of the Jones River Watershed in its current state is complex due to: (a) large-scale interbasin transfers associated with Silver Lake; (b) the vast amount of stratified drift which enables a fairly constant discharge of groundwater (base flow); (c) and the utilization of water resources for agricultural purposes. EOEA Build-out projections indicate the potential for development is very high, and therefore the future demand for water resources will be an important part of the planning process for the communities dependent on the water resources of the Jones River Basin.

A substantial amount of work in the basin has been conducted by the USGS, concentrating on aquifer yields / baseflows and groundwater quality both in the watershed and the nearby Plymouth-Carver Aquifer. There is also a USGS stream gage on the Jones River at the Elm Street Dam with a 34-year period of record. The previous studies summarized in this document and GZA's analysis of the stream gage data indicate a fairly "flat" flow-duration curve, an indicator that the flow in the Jones River at the USGS stream gage is fairly constant due to a very high contribution of base flow (i.e., groundwater runoff) to the total streamflow. Base flow measurements in the summer of 1987 indicated larger contributions of flow from subbasins including Halls Brook, Furnace Brook, and Smelt Brook in comparison to the Upper Jones River, Jones River Brook, and Pine Brook, despite somewhat homogeneous land use and general surficial geology characteristics. The larger amount of base flow is likely attributable to the greater extent of underlying high-yield aquifer in the Halls Brook, Furnace Brook, and Smelt Brook subbasins. Lower flows in the Upper Jones River are due largely in part to the diversion from its headwaters, Silver Lake, as part of the City of Brockton's water supply.

The Jones River Watershed Association, with assistance from the Commonwealth of Massachusetts, has been active in surveying and investigating the aquatic habitat of the watershed. Recent studies have identified and assessed fish populations within the Jones basin, mussel populations around Silver Lake, and conducted macroinvertebrate bioassessment throughout the watershed. Fisheries surveys indicate species expected in a low-gradient Southeastern Massachusetts Coastal stream. Typically, the health of these populations are often limited by low flow conditions, as GZA discovered in the Weir River Watershed in the Hingham, Massachusetts area.[42]

The watershed is also an important resource to both its residents and those outside of the watershed in Brockton, Hanson, Whitman, and Marshfield that depend on its water resources for their drinking water supply. Legislation passed in 1899 has granted the City

[42] GZA GeoEnvironmental Inc., "Status of and Potential Impacts on Water Budget for the Weir River Watershed," June, 2002.

of Brockton the right to withdraw from Silver Lake. Between October and May, water is diverted to Silver Lake from outside of the basin (average of 8.4 MGD). The interbasin transfer of water from Silver Lake to the Brockton service area amounted to an average of 10.25 MGD according to the 1996 through 2000 Public Water Supply Statistical Reports. Data maintained by the City of Brockton, included in Appendix E, indicates that the Lake level fluctuates significantly, as would be expected in a surface-water supply, and for the majority of the year is below the spillway crest level of Forge Pond Dam, which controls outflow from the Lake to the Upper Jones River. Other water supplies are obtained from the basin, amounting to approximately 1.3 MGD from the 7 wells owned and operated by the Town of Kingston, 0.13 MGD from the Lake Shore well operated by the Town of Duxbury, and 1.24 MGD from the well within the watershed operated by the Town of Pembroke, as of 2000.

Additionally, the 737 acres of cranberry bogs need, but do not necessarily consume, up to 15.8 MGD of water per year. A large amount of this water need occurs during the non-growing season for frost protection floods or harvest floods, and is likely a non-consumptive use. Irrigation usage or other flooding of bogs which occurs during the growing season does subject the water to the effects of evapotranspiration. The WMA considers the water need as the volume of water for which a cranberry bog must register or obtain a permit. Using a guideline of about 10 acre-feet of water per year per acre of bog, the WMA requires bogs of greater than 4.66 acres to obtain a permit for 0.1 MGD of water usage. Although the water need of cranberry bogs is not necessarily entirely a consumptive use, during the time in which the bogs are flooded, impounded, or otherwise diverting water, they can alter the natural flow regime of their receiving/source streams. Bogs are expected to consume an amount equivalent to potential evapotranspiration during the non-winter season, or about 26.5 inches per year.

7.20 INFLOW/OUTFLOW ANALYSIS FINDINGS

The August median flow as measured at the USGS stream gage on the Jones River at Elm Street is about 0.7 cfsm. The contributory watershed to the USGS gage and each subbasin of the Jones River meets or exceeds the USFWS aquatic base flow of 0.5 cfsm on a year-round basis, with the exception of Pine Brook (0.3 cfsm in August). The surface waters of the watershed are fed on a relatively constant basis by groundwater, as indicated by the flow-duration curve developed at the USGS gage and as reflected in GZA's water budget analysis.

As expected, current estimated flow rates in the watershed are slightly less than natural flow rates as a result of water withdrawals for drinking water supply and agriculture. The nature of the land use in the watershed (mostly wooded) does not lend itself to large amounts of impervious area that could significantly reduce baseflows. The Aquatic Habitat Safe Yield (AHSY) for the entire Jones River watershed exceeds the amount of registered and permitted withdrawals in the watershed and for the majority of the subbasins. Summer AHSY range from a low of 0.0 MGD in Pine Brook to a high of 3.2 MGD in Smelt Brook, given a target in-stream flow of 0.5 cfsm (the USFWS summer aquatic base flow goal).

Both the Pine Brook and Silver Lake subbasins contain withdrawals in exceedence of the AHSY. However, in the case of Pine Brook, the natural hydrology does not appear to meet the USFWS 0.5 cfsm standard. The Aquatic Habitat Safe Yield calculations have been made on the basis of a year with average precipitation and evaporation rates. The infrastructure needed to utilize the maximum groundwater and/or surface water available from all sub-basins does not currently exist; therefore the Aquatic Habitat Safe Yield estimated in this report is higher than is currently feasible. Once again, it must be noted that the Aquatic Habitat Safe Yield estimated by this study is does not refer to physical capability of supply systems to actually withdraw water from the watershed. No long-term operations study or simulation was undertaken to estimate reliability of the systems to meet demand; nor were the capacities of individual wells, pumps, treatment plants, or storage tanks taken into account. More information regarding Silver Lake is provided in Section 7.30.

Silver Lake once served as a continuous source of flow for the Upper Jones River. Since its development for water supply at the turn of the 19th century, the volume of contributory flow from the Lake to the Jones River has varied seasonally and with water demand. As a result, the current contribution of the Lake is negligible when the lake elevation drops below the spillway elevation of Forge Pond Dam.

Additional detailed discussion of Silver Lake is provided in Section 7.30. Additional detailed conclusions regarding the inflow/outflow analysis are provided in Section 5.40.

7.30 RECOMMENDATIONS

Overall, the majority of the Jones River watershed currently contains adequate flow rates to support aquatic habitat and the current (and predicted future) level of water withdrawals and development, as indicated by comparisons of GZA's water budget-estimated existing subbasin flows with recommended USFWS in-stream flow targets. The USFWS in-stream aquatic base flow (ABF) policy recommends instantaneous flows for New England streams of 0.5 cfsm year-round, excepting 1.0 cfsm in the fall/winter and 4.0 cfsm for the spring for applicable spawning and incubation periods. In the absence of detailed IFIM analyses, the USFWS ABF policy is applicable to the Jones River watershed and watershed-specific August median flows of 0.7 cfsm as calculated from data taken by the USGS at the stream gage at Elm Street are near the 0.5 cfsm USFWS standard. It is possible that alternate flow targets to this particular standard may be appropriate for habitat conservation in the Jones River. A more quantitative and predictive analysis such as a Physical Habitat Simulation (PHABSIM) model may be appropriate to more precisely target a flow range that is suitable for aquatic habitat and balances out of stream water use (Bovee, *et al*. 1998). It must also be noted that flow goals in the watershed are also a function of stakeholder and regulatory consensus, and as such goal setting is as much political as it is scientific.

7.31 Silver Lake

Silver Lake supports the majority of the City of Brockton's water demand, which is on average about 10 MGD. The water supply operations at Silver Lake were instituted in 1899 and result in seasonal water surface elevation fluctuations that, in turn, limit the amount of outflow to the Upper Jones River, particularly in the summer months. The City has legislative authority to divert water from out-of-Jones-watershed Furnace and Monponsett Ponds to Silver Lake from October through May. The legislative Acts enabling Brockton to withdraw water from Silver Lake and divert the waters of Furnace and Monponsett Ponds to Silver Lake did not specify minimum releases to the Jones River. As a result, the natural flows from Silver Lake to the Jones River, estimated by GZA to vary from about 5 cfs to 40 cfs prior to the establishment of human activity, are currently non-existent for much of the year. As would be expected in any water body which serves as a water supply, the elevations in the Lake vary widely: as much as 6 feet in the 1990s. The headwaters of the Jones River experience insignificant flows from the Lake when the water surface elevation of Silver Lake / Forge Pond are lower than the spillway elevation at Forge Pond Dam. Natural flows from the Lake are estimated to be 1.7 cfsm (about 7 cfs) during August, as compared to field-estimated flows of near zero during current August conditions. The lack of flow has an adverse impact to the amount of aquatic habitat available in the Upper Jones River, and affects the portion of the Jones River from the Forge Pond Dam until the point downstream where groundwater/tributary contributions allow for measurable flow in the channel (observed to be about 1,000 ft downstream of Forge Pond Dam during the Fall of 2001).

It should be noted that Brockton's water conservation practices and other socio-political management practices have reduced the pressure on Silver Lake as Brockton's water demand has fallen to 10 MGD. Population projections for the year 2020 indicate an expected decrease in Brockton's population, which subsequently result in lower water demand projections. Brockton also continues to look for alternate water supply sources in addition to controlling water demand, as Silver Lake is already stressed in terms of providing a stable drinking water supply to the City of Brockton (reported firm or safe yield estimates for the Silver Lake system range from 8 to 10 MGD, while historic average water demands have often exceeded 10 MGD). Specifically, the development of Avon Reservoir, Taunton River watershed well development, and perhaps most significantly, the preliminary agreement with the Bluestone desalination project in Dighton, Massachusetts could alleviate the water demands upon Silver Lake. GZA recommends that the City of Brockton continue to work with the DEP and local stakeholders to ensure a reliable water supply in the future from both a traditional safe yield aspect and an aquatic habitat safe yield aspect.

To restore flow to the Upper Jones River from Silver Lake, GZA recommends that the feasibility of installing a low level outlet from Forge Pond Dam be investigated. The release of additional waters from Silver Lake would obviously impact the available yield of the Lake for water supply purposes, which must be taken into consideration. It may also serve to create lower Lake levels and reduce the already infrequent overflow from the

Forge Pond Dam spillway. However, a constant or seasonally-variable release of water from Silver Lake would restore the aquatic habitat of the Upper Jones River and provide the means for fish migration from downstream areas. Further site-specific study from both an engineering perspective (regarding the modification of Forge Pond Dam) and an ecological perspective (regarding the variation of water surface elevations upon lake-dependent and riverine species) is required to assess the advantages and disadvantages to humans and aquatic species of such low-level releases.

7.32 Pine Brook

Pine Brook is anticipated to be the least water-rich subbasin in the watershed, partly as a result of its natural geology. While most of the other subbasins are underlain by large coarse sand and gravel deposits, Pine Brook reportedly is not[43]. As a result, natural flows are expected to range from 0.3 cfsm to 1.0 cfsm, which is, at its lowest, below the USFWS target in-stream flow rates. Pine Brook has an AHSY of 0.0 MGD, given an in-stream USFWS target summer flow of 0.5 cfsm. Compounding the situation, extensive agricultural development (Upper and Lower Chandler Ponds and other cranberry bogs) and a municipal water supply well in the basin operated by the Town of Duxbury are expected to affect or regulate flows. Since the volume of streamflow depletion due to the Duxbury well is nearly negligible (0.1 cfs to 0.2 cfs), it is more likely the diversions and withdrawals associated with bog activity are a greater influence on local flow regimes. Further study than that allowed for in the scope of this project is required to inventory the nature of aquatic species and to evaluate the site-specific impacts to aquatic habitat in this subbasin, if any, as a result of the estimated low flows. The hydrology and geology of the basin may also be further explored, particularly to investigate the extent of the contributing aquifer area and to refine flow conditions in the brook.

Previous studies including the JRWA Silver Lake and Jones River Watershed Study and the DEM’s 1991 South Coastal Basin plan had recommended year-round minimum instantaneous flows for Pine Brook of 1 MGD (1.55 cfs or 0.32 cfsm). This recommendation, while lower than the USFWS target, approximates the estimated natural baseflow for Pine Brook. Thus, a more appropriate management goal may be to use estimated natural base flows and/or stream flows to set target in-stream flows.

7.33 Fish Passage

The Jones River is a coastal stream which has the capacity to support anadromous fish. Species such as alewife and blueback herring have been observed a the Elm Street Dam, which has a fish ladder at its right abutment. Upstream of Elm Street Dam, the Wapping Dam, near Wapping Road, precludes any further upstream migration of anadromous fish that may have successfully navigated past the Elm Street Dam. Forge Pond Dam, at the outlet of Silver Lake, also does not have provisions for fish passage. Since Anadromous fish are habitat generalists, the aspect of adequate flow depths and fish passage obstructions are of greater import than specific habitat criteria such as substrate

[43] USGS, 1991.

type, channel sinuosity, etc. If the watershed is to be managed as an anadromous fish run, the feasibility of constructing fish ladders at the Wapping Dam and Forge Pond Dam should be studied. As a potentially more effective alternative in regard to fish passage, the feasibility of decommissioning the Wapping or Forge Pond Dam may be further investigated. Several smaller dams associated with cranberry bogs are also present in the streams of the watershed. Massachusetts, through its River Restore program, has been increasingly active in assisting public and private entities with the regulated breaching of obsolete dams, including the Old Berkshire Mill Dam on the East Branch of the Housatonic River in Dalton, the Billington Street Dam in Plymouth, and the Mill Pond Dam in Hanover / Norwell. If either the Wapping Dam or the Forge Pond Dam is found to be limited in its usefulness and unimportant from an environmental or historic perspective, dam breaching would provide a more desirable fish passage scenario than the installation of fish ladders.

Similar situations exist at other subbasins in the watershed such as the Smelt Brook, Halls Brook, and Furnace Brook watersheds. Assessing the feasibility of restoring anadromous fish runs should be investigated on a brook-by-brook basis, taking into consideration both engineering and ecologic considerations.

7.34 Detailed Groundwater-Surface Water Interactions / Additional Studies and Data Collection

To further identify the extent of the contributory groundwater watershed, additional detailed analysis is required. This is particularly true of the southern portion of the Jones River Watershed (i.e., Smelt Brook, Furnace Brook, and Jones River Brook), where the basin overlies the northern fringes of the Plymouth-Carver aquifer. It is possible that groundwater divides and surface water divides do not coincide, and this may impact the recharge area for each subbasin and, subsequently, the flows expected in each sub-watershed. Similarly, to consider detailed hydrologic effects in the watershed such as soil moisture or inter-connected impervious area that may have some influence on current flows in relation to natural flows, a continuous flow model such as HSPF is needed. The detailed models which may operate on a daily basis require much more data for input, calibration, and verification than was possible given the resources of this project.

Sub-watershed water budget models were not directly calibrated and verified due to a lack of continuous flow data in these sub-watersheds. Long-term, continuous flow data (as opposed to “snap-shots” of flows that were gathered in this study) are required to verify the subbasin models developed in this study. Additionally, development of recording precipitation and pan-evaporation stations within the watershed may also generate site-specific data that may lead to model refinement. This is particularly the case as it relates to evaporation estimates, as the nearest site (and the closes site reflective of the Jones River watershed, in our opinion) that provided reliable pan evaporation data was in Kingston, Rhode Island. Further study of cranberry bog evapotranspiration and consumptive water use would also be useful in future model refinement.

Although the USFWS ABF Policy is likely sufficient for flow goal-setting in the watershed as judged by the proximity of the 0.5 cfsm summer flow standard to the 0.7 cfsm August Median Flow as estimated at the USGS stream gage at Elm Street, a detailed IFIM analysis may provide slightly different flow targets.

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9.00 GLOSSARY

Aquifer: A geologic formation, group of formations, or part of a formation that contains sufficient saturated permeable materials to yield significant quantities of water to wells or springs

Baseflow: The portion of streamflow derived from groundwater discharge.

Bedrock: Solid rock, commonly called "ledge," that forms the earth's crust.

Casing: Any construction material that keeps unconsolidated earth materials and water from entering a well.

Coagulation: The process by which material clumps together or becomes viscous or thickened.

Coefficient of Permeability: The rate of flow of water (in gallons per day) through a cross sectional area (of one square foot) of a saturated material under a hydraulic gradient (of one foot per foot) at a Temperature of 16^{o} C.

Coliform Bacteria: Any of a group of bacteria, some of which, inhabit the intestinal tracts of vertebrates. Their occurrence in water is regarded as evidence of possible contamination.

Color Unit: A standard of color in water measured by the platinum-cobalt method. The color produced by 1 mg/L of platinum in water equals 1 color unit.

Cone of depression: A depression produced in a water table by the withdrawal of water in an aquifer.

Cubic feet per second, cfs: A unit expressing discharge. One cubic foot per second is equal to the discharge of a stream 1 foot wide and 1 foot deep flowing at an average velocity of 1 foot per second.

Direct Runoff: Water that moves over the land surface directly into a receiving stream or water body shortly after a precipitation event.

Dissolved Solids: The residue from a clear sample of water after evaporation and drying for one hour at 180^{o} C.

Draft Rate: A rate of regulated flow at which water is withdrawn from storage in a reservoir.

Drawdown: The lowering of the water table or potentiometric surface caused by the withdrawal of water from an aquifer by pumping; equal to the difference between the static water level and the pumping water level.

Eutrophic lake: A lake rich in dissolved nutrients, commonly shallow and having seasonal oxygen deficiency.

Evapotranspiration: Loss of water to the atmosphere by direct evaporation from water surfaces and moist soil combined with transpiration from living plants.

Flocculation: The process by which clumps of material in a liquid aggregate or increase in size.

Flood: Any high streamflow overtopping the natural or artificial banks in any reach of a stream.

Flow duration: In a stream, the percentage of time during which specified daily discharges have been equaled in magnitude within a given time period.

Fracture: A break or opening in bedrock along which water may move.

Frequency: The average number of extreme events over a period of many years.

Gaging station: A site on a flowing body of water for systematic observations of water height or discharge.

Gravel: Unconsolidated rock debris comprised principally of particles larger than 2 mm in diameter.

Groundwater: Water in the saturated zone (subsurface).

Groundwater divide: A hypothetical line on a water table on each side of which the water table slopes downward in a direction away from the line.

Groundwater outflow: The sum of groundwater runoff and underflow; it includes all natural groundwater discharge from a drainage area exclusive of groundwater evapotranspiration.

Groundwater recharge: Amount of water added to the saturated zone through infiltration.

Groundwater runoff: Water that has discharged into stream channels by seepage from saturated earth materials.

Head, static: The height of the surface of a water column above a standard datum that can be supported by the static pressure at a given point.

Hydraulic boundary: A physical feature that limits the areal extent of an aquifer. The two types of boundaries are termed impermeable barrier boundaries and line-source boundaries.

Hydraulic conductivity: A measure of the ability of a porous medium to transmit a fluid. The ratio of velocity to hydraulic gradient, indicating permeability of a material. The material has a hydraulic conductivity of unit length per unit time if it will transmit in unit time a unit volume of water at the prevailing kinematic viscosity through a cross section of unit area, measured at right angles to the direction of flow, under a hydraulic gradient, of unit change in head over unit length of flow path.

Hydraulic gradient: The change in static head per unit of distance in a given direction.

Hydrograph: A graph showing stage (height) versus discharge with respect to time.

Impermeable barrier boundary: The contact between an aquifer and adjacent impermeable material that limits the areal extent of the aquifer.

Induced infiltration: The process by which water infiltrates an aquifer from an adjacent surface water body in response to groundwater pumping.

Induced recharge: The amount of water entering an aquifer from an adjacent surface water body by the process of induced infiltration.

Interflow: Subsurface flow through pipes and pores in the soil.

Line-source boundary: A boundary formed by a surface water body that is hydraulically connected to an adjacent aquifer.

Partial record gaging station: A site at which random measurements of stream elevation or flow are made at irregular intervals.

Perennial stream: A stream that flows during all seasons of the year.

pH: The negative logarithm of the hydrogen-ion concentration. pH of 7.0 indicates neutrality; pH below 7.0 denotes acidity, above 7.0 denotes alkalinity (base).

Porosity: The property of rock or unconsolidated material to contain voids or open spaces; it may be expressed quantitatively as the ratio of the volume of its open spaces to its total volume.

Precipitation: The discharge of water from the atmosphere, either in a liquid or solid state.

Recurrence interval: The average interval of time between extremes of streamflow, such as floods or droughts, that will at least equal in severity a particular extreme value over a period of many years.

Runoff: That part of precipitation that appears in streams.

Saturated thickness: Thickness or depth of an aquifer below the water table.

Saturated zone: Subsurface zone in which all open spaces are filled with water. The water table is the upper limit of this zone.

Sediment: Fragmental material that originates from weathering of rocks.

Specific capacity of a well: The rate of discharge of water divided by the corresponding drawdown of the water level in the well.

Specific yield: The ratio of the volume of water which, after being saturated, a rock or soil will yield by gravity, to its own volume.

Storage coefficient: The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. In an unconfined aquifer, the storage coefficient is virtually equal to the specific yield.

Stratified drift: A predominantly sorted sediment laid down by or in meltwater from a glacier; includes sand and gravel and minor amounts of silt and clay arranged in layers.

Streamflow: Discharge of water along a defined channel. The sum of baseflow, interflow, and runoff.

Subbasins: Hydrologic divisions of a watershed.

Transmissivity: Measure of how easily water in an aquifer can travel through its porous material. Equal to the hydraulic conductivity times the saturated thickness.

Transpiration: The process whereby plants release water vapor to the atmosphere.

Turbidity: The extent to which penetration of light is restricted by suspended sediments, microorganisms, or other insoluble material.

Unconfined aquifer: (water table aquifer) An aquifer whose upper surface of the saturated zone is at atmospheric pressure and free to rise and fall.

Unconsolidated: Loose, not firmly cemented or interlocked.

Underflow: The downstream flow of water through the permeable deposits that underlie a stream.

Unsaturated zone: The zone between the water table and the land surface in with the open spaces are not entirely filled with water on a permanent basis.

Water divide: Point where the water table is at a maximum and flow does not cross.

Water table: The upper surface of the saturated zone.

Watershed: Area of land that drains to a single outlet and is separated from other watersheds by a divide.

Well: Vertical hole dug into the soil that penetrates an aquifer and is usually cased and screened.

Well screen: Slotted casing that allows water to enter a well from the aquifer.